Engineering For Land Drainage

A MANUAL FOR
THE RECLAMATION OF LANDS
INJURED BY WATER

By

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PREFACE TO THE THIRD EDITION

IN this, the third edition of "Engineering for Land Drainage," the author has revised some parts and added to others to make the book more useful to students and to drainage engineers. The discussion of the hydraulics of flow in underdrains has been rewritten, and new tables for the discharge of tile drains have been introduced which it is believed correspond quite closely to results obtained in practice. A diagram to facilitate the application of Kutter's formula in the design of ditches and canals has been added, as well as historical drainage matter, and a more complete text on drainage by pumps and on the drainage of irrigated lands.

C. G. E.

WASHINGTON, D. C., *May, 1919.*

PREFACE

SINCE the preparation of the first edition of this book in 1902, the development and extension of land drainage have been continuous and substantial. In the course of this progress much additional data of use to engineers have become available. Increased demand for engineering service in reclamation projects has drawn into the field those with more or less experience in other branches of engineering as well as many just out of college. These are seeking the best information obtainable upon the underlying principles of drainage and methods of work.

This edition of "Engineering for Land Drainage" is a new book, having been entirely rewritten. It embodies the essential features of drainage engineering in this country at the present time, with the latest developments along each line, and is adapted to the use of the professional engineer and the student.

The publications of Drainage Investigations of the U. S. Department of Agriculture are an important addition to the drainage literature of the day, and I am indebted to them for much helpful data and useful information for which credit is given wherever used in this work.

I take this opportunity to cordially thank A. D. Morehouse, Assistant Chief of Drainage Investigations, Arthur E. Morgan and L. L. Hidinger of the Morgan Engineering Firm, Memphis, Tenn., and S. M. Woodward, Professor of Hydraulics, Iowa State University, for valuable suggestions; and also, to express my deep obligations to my wife for her service in completely editing the manuscript and correcting the proof.

WASHINGTON, D. C. CHARLES G. ELLIOTT.

November, 1911.

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CHAPTER I

DEVELOPMENT OF LAND DRAINAGE

THE importance of agricultural drainage will in a measure be appreciated when we consider the number and magnitude of land-drainage projects which have been worked out during the century which has just closed. The immense tracts of land in the Old World which have been reclaimed from the inroads of river and sea, and are now great food-producing lands, furnish abundant evidence of the skill of the engineers who planned and directed the work, and of the energy and persistency of the people who were responsible for its execution.

The English Fens. The Fens of Eastern England, comprising over 680,000 acres of land which was formerly periodically inundated by the storm-tide of the North Sea and by rivers which discharged the waters of the interior of the island upon them, are now productive lands, dotted by thrifty towns and traversed by railroads of national importance. Their reclamation, which extended over a period of two centuries, was attended with difficulties and discouragements which have rarely been exceeded in the attempt of any people to enlarge its agricultural domain.

The name is of Anglo-Saxon origin, corresponding in meaning to our marsh or swamp, and has come to be applied almost exclusively to the great level delta of Eastern England. The lands belonged originally to the Crown and were partially occupied by a hardy race called Fenmen who, at the close of the Roman occupation, 420 A.D., began to settle in what was then called the Fenland. A slightly elevated place was selected by some family or tribe and surrounded by a bank to secure it from winter floods. This formed the nucleus of a colony which used the low lying lands for the grazing of stock and the wilder and more swampy portions for hunting and fishing. The Fenmen led a precarious life, their dwellings being subject to overflow by water which came down from the rivers and by the extremely high tides which have always been a menace to the coast lands of the North Sea. At such times the entire Fenland was submerged and the inhabitants with their cattle were obliged to seek a refuge on higher land.

The people who occupied these lands were what we would call "squatters." They paid no rent but occupied the lands by sufferance of the Crown. When the Crown granted to others, at that time called "adventurers" or "undertakers," the right to reclaim the lands, they were regarded by the Fenman as usurpers and enemies and often destroyed costly dikes and sluices after the lands had been drained and successfully cultivated.

The Fens a National Asset. While the reclamation of the Fens, which was worked out slowly and under great difficulties, was of great national importance, no government assistance nor protection was given to those who had the courage to undertake the drainage of any part of them. The King granted to certain individuals at various times the right to reclaim tracts of land and

to receive as remuneration for their labor and expense title to a portion of the reclaimed area, usually about one-third or one-fifth part. Great losses were sometimes suffered by these enterprising men by reason of the failure of the Government to secure them from the depredations of the hostile Fenmen. The productive possibilities of these lands had been proven quite early in their history. During the time they were in possession of the Romans, great quantities of grain were grown on the borderlands and shipped out to supply their armies. It is related that in 359 A.D. a large fleet of vessels was built in the upper Rhine for the purpose of transporting food to the armies and as soon as completed was sent to Britain and loaded with wheat.

Since their reclamation, the "lowlands," or "black lands," of Eastern England have remained a constant source of grain supply for the empire and as such are destined to be an area of national importance. Viewed from the standpoint of the individual farmer, agriculture in the Fens has been subject to uncertainties and disappointments. The history of the various stages of the improvement discloses the fact that the profits from farming, and consequently the value of the land, have fluctuated greatly, due to causes which may develop in any country. Land values in England are measured by annual rentals. Land is worth to the owner what rental the tenant can pay. That amount depends upon the cost of labor, the crop yield of the land, and the price he gets for his product. A series of wet seasons and unfavorable climatic conditions lower rentals as do also low prices of products for a term of years.

As to the increase in the value of lands in the Fens as a result of their reclamation, there is no question, notwithstanding the fact that we have no figures that show the actual total cost of the work. W. H. Wheeler

discusses this subject quite fully in his "History of the Fens of South Lincolnshire." The value of the Fens in the middle of the seventeenth century, before attempts were made to reclaim them, was estimated at about eight cents an acre (rental). After the work then planned was completed as stated in a petition made to the House of Lords, the value of the land was $3 to $3.75. A century later, soon after the enclosure and reclamation of what was known as the Holland Fen, a member of the Enclosure Commission placed the annual per acre value of 22,000 acres at $3.75, the value before improvement having been about 75 cents. In 1849 Mr. Clark, of the Royal Agricultural Society, estimated the Fenland at $10 an acre. From 1875 to 1895, there was a marked depression of agriculture in England, during which time, according to several authoritative reports, rentals fell off 25 per cent to 40 per cent. The decline is accounted for first by a series of wet seasons, 1874 to 1882, during which time the land deteriorated in production, and, secondly, to the decline in the price of products, particularly between 1882 and 1895. During the long time in which the reclamation of the land was being worked out, the drainage was frequently shown to be deficient and the dikes and banks unable to withstand the erratic and violent high tides of the North Sea. The works were constructed by hand labor, often with insufficient funds. Discouraging losses occurred. It was only through the persistence of successive generations that the Fens have been brought to their present value and security against the ravages of tide and weather.

The Black Sluice District. To illustrate some of the features of Fenland drainage, a map of the Black Sluice District,* which is tributary to the Witham River in

* From Wheeler's "History of the Fens of South Lincolnshire."

South Lincolnshire, is shown in **Fig. 1.** It is a strip of level marsh, the southern part originally a lake, about four miles wide and twenty-one miles long. The

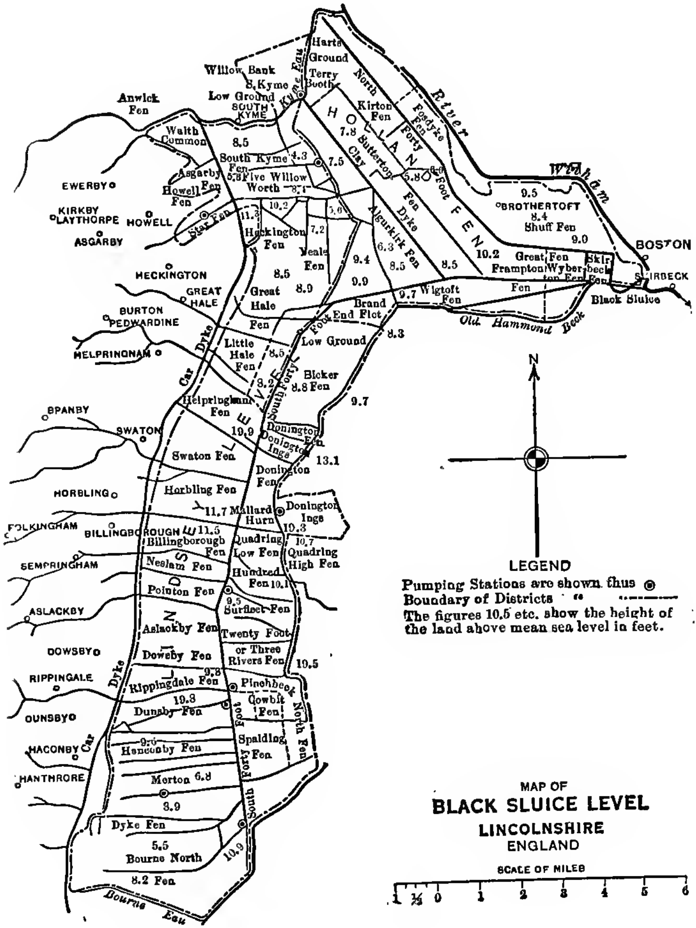


FIG. 1.

taxable area of the district is 64,854 acres, but the total area of land which discharges its water into the ditches and through the outlet sluice into the Witham River is 134,351 acres. This area passed through successive stages of improvement from 1633 to 1886, at which latter date the system which is now in operation was perfected. It is here proposed to briefly state some facts and lessons which we may derive from the history of those works.

The main drain, called the "South Forty Foot," is 21 miles long, has a grade of 3 inches per mile, and discharges into tidewater near Boston through the Black Sluice, which has three gates each 20 feet wide. The interior drainage is accomplished through the organization of small districts bearing local names, as "Morton Fen," "Dowsby Fen," etc., which use the main drain as an outlet and pay a tax for its construction and maintenance. The amount of tax for the construction of the main drain was assessed on the theory that the land most distant from the outlet should pay the greater tax.

It was learned in this district, as well as elsewhere in the Fens, that the common effect produced on all Fenlands by improved drainage is a general subsidence of the soil. The removal of water from the land causes the spongy soil to consolidate or shrink gradually and the process is further assisted by plowing and cultivating the land. The organic matter accumulated during many centuries decomposes by being exposed to the atmosphere, and a general result is a lowering of the level of the surface of the ground. Owing to this natural and now well understood effect, gravity drains which were effective for a term of years lost their value and some of the districts were compelled to install pumps to lift the water from the lowlands into the main

ditch. Numerous pumping stations are now operated to accomplish the drainage that is desired. Wheeler states that these lands have settled from 4 feet to 6 feet since 1743. The results of observations quoted by Mr. Wheeler are that the Fens in general have shrunk from 5 feet to 8 feet since their reclamation began.

The uplands, comprising about 70,000 acres, shed their surplus waters into the district through small streams, which in some cases are carried across the Fens on a higher level and discharged directly into the "South Forty Foot." Such streams carry "live water" from the hills and are called "lodes." During dry seasons water is taken out of the "lodes" through small gates to replenish the drainage ditches to prevent the land from becoming too dry. It is generally conceded that the water table in peat lands should be kept within 24 inches to 30 inches from the surface. The hill lands have a chalk subsoil which rapidly absorbs the rainfall and substantially lessens the surface run-off that would otherwise take place. As a result, a considerable and constant supply of seepage water appears at the base of the slope where it is intercepted by a ditch called the "Car Dyke," which extends along the base of the slope and discharges its water into the river through an independent sluice.

The elevation figures on the map show how low the land is and the little fall that the drains have. Long and costly experience has shown that all of the ditches must be kept free from obstructions at all times, or they will fail to lead the water to the outfall.

Haarlem Lake, Holland. The Dutch people have been looked upon in modern times as masters of the science and art by which an important part of their dominion has been recovered from the sea. The drainage of Haarlem Lake is a striking example

of their ability and painstaking skill in this field of activity.

Haarlem Lake was a body of fresh water oblong in shape, about 14½ miles long, 8 miles at its greatest width, and 13 feet deep. It was separated from the North Sea by a strip of land 5 miles wide, one-third of which was fertile land and the remainder sand-dunes sparsely covered with scrubby trees. Opposite the north end, about one mile distant, is the city of Haarlem, and on the east, 4 miles distant, is Amsterdam, the capital and metropolis of the kingdom. The lake, covering an area of 43,700 acres, was made to serve as a collecting basin for waters of the surrounding lands which were drained. Owing to severe storms, which rendered the overflow sluices insufficient, and to heavy rainfall in that country, the lake overflowed at times to the great injury of the adjoining lands. In consequence of this damage the States-General in 1839 decreed the drainage of the lake and appropriated $2,235,000 to carry out the work, and placed this work in charge of a Commission of thirteen, composed of engineers, landowners, and state counsellors. Prior to beginning operations under the commission, the details of the entire plan which was finally adopted were carefully worked out. A survey of the bottom of the lake was made from the surface of the ice and the total volume of water that it would be necessary to pump was estimated, including the increase from rainfall and seepage. The size and arrangement of ditches, number and location of pumping stations, as well as the power that would be required to empty the lake, were carefully estimated.

The plan was to build a bank or levee entirely around the lake, a distance of 37 miles, and construct outside of this a navigable canal into which the water of the lake

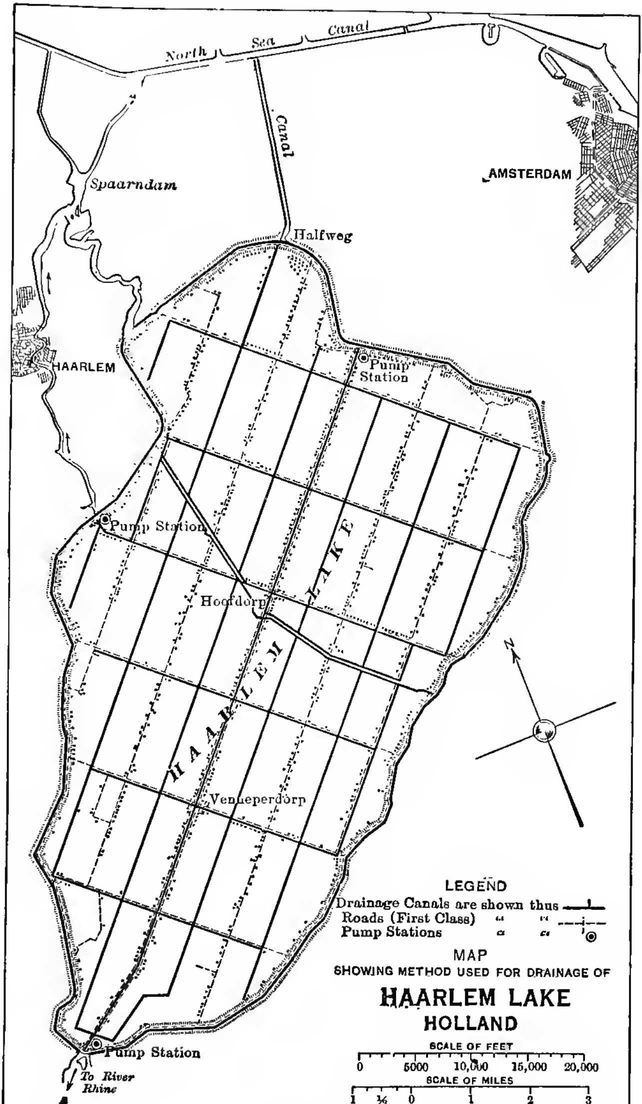

North Sea Canal
Canal
AMSTERDAM
Spaarndam
Halfweg
HAARLEM
Pump Station
Pump Station
Hoofdorp
HAARLEM LAKE
Venneperdorp
Pump Station
To River Rhine
N
LEGEND
Drainage Canals are shown thus
Roads (First Class) " "
Pump Stations " "
MAP
SHOWING METHOD USED FOR DRAINAGE OF
HAARLEM LAKE
HOLLAND
SCALE OF FEET
0 5000 10,000 15,000 20,000
SCALE OF MILES
1 ½ 0 1 2 3

FIG. 2.

was to be pumped. When the water in the canal should become higher than the navigable level, the surplus would pass northward to the North Sea Canal through gates at Spaarndam and at Halfweg, and southward to the river Rhine through those at Katwig. The dimensions of this canal were as follows:

Width of bottom	95 ft.
Width of top	140 "
Side slopes	2 to 1
Top of bank above high water	9.6 ft.
Depth of canal from top of bank	17.4 "
Width of top of bank	13 "

A roadway was located between the canal and the levee. The canal occupied 665 acres and the bank with its slopes and the road 1,030 acres. The levee and canal were begun in 1840 and finished, except the closures, in 1843. Owing to delays in the adjustment of the rights of the owners of the surrounding lands which had formerly drained into the lake, the closures were not completed until 1848. The cost of the levee and canal was $807,500.

Three pumping stations were located: one at the north extremity of the lake, one at the south, and one at the west side, each to have a 350 horse-power plant. Each plant consisted of a group of plunger or bucket pumps operated by huge reciprocating beams. The first of these was set up at the south end of the lake in 1845 and thoroughly tested. The engine worked 11 cylinder pumps, each 63 inches in diameter, the plunger having a 10-foot stroke and a speed of 10 strokes per minute. One stroke of the 11 pumps combined will lift 2,376 cubic feet of water a height of 16½ feet. In a run of twenty-four hours 1,069,000 tons of water are raised and delivered on a large floor from which it flows in a cascade into the receiving canal at the side.

Similar pumps with 8 cylinders each were placed at the other two stations. The lake was pumped dry in July, 1852, the plants combined having been operated 39 months. It is claimed that the actual working time of the pumps was only 19½ months. The total quantity actually pumped was 831,000,000 cubic meters against 764,000,000 originally calculated.

In establishing the depth of the ditches, it was decided to fix the height of water level at 30 inches for grass and pasture lands, and 40 inches for cultivated land. Some portions of the lake bottom are sandy and there it has been found desirable to allow the water to rise within 24 inches of the surface. Since settling takes place after the water has been removed from the soil, 13½ inches were allowed for shrinkage.

Two main drains 82 feet wide on the bottom were made, one north and south through the middle of the lake bottom, and the other east and west across it leading to the three pumping stations. Main ditches were made parallel to the trunk drains which lead to the pumps, each being 18 inches less in depth, and 26 feet wide on the bottom. Those running north and south were 1¼ miles apart, and those east and west were placed 2 miles apart. The grades of the ditches were level, the velocity of flow being produced by the slope of the surface of the water, caused by drawing the water down at one extremity. Two inches slope per mile is allowed, and is considered sufficient to produce the required velocity. The land between the main ditches was then divided by boundary ditches into fields of 50 acres. Roads were located midway between the main ditches north and south, each having a large ditch on one side, and a small one on the other. Roads were also made along the east and west ditches. The water line of the soil in the fields distant from the main drains is economi-

cally controlled by making the distant ditches of less depth than the mains, so that when the water is lowered to the desired limit in the main the smaller ditches will be nearly or quite empty.

The extent of the works which were required in the reclamation of Haarlem Lake may be concisely stated as follows:

Length of encircling canal and levee	**37**	**miles**
Total length of large collecting canals leading to pumps	**18.6**	**"**
Total length of main canals	**93.1**	**"**
Total length of all canals and drains	**750**	**"**
Total length of roads	**122**	**"**
Number of bridges	**65**	
Number of pumping plants	**3**	

The works for the drainage of the lake deliver the water into the "Ringvart," or encircling canal. During the greater part of each year the surplus from the canal flows by gravity through sluices into the North Sea Navigation Canal, but during a part of every year the surplus must be lifted by pumps a second time. For this purpose a large pump is located at Halfweg, at the northern extremity of the lake, that raises water into a canal that connects with the North Sea Canal; a second at Spaarndam, which sends the water into the same canal, and the other at Katwig, which controls the height of the canal at the south end of the lake. The pumps at these stations are of the Scoop Wheel type operated by steam. A part of the expense of operating these secondary stations is charged against the property in the lake.

This account would lack an essential feature if a statement of the cost were omitted. After the reclamation was completed the lake bottom was sold by the Government at public auction, at prices ranging between

$63 and $130 per acre, the average price for the entire lake bed being $80 an acre.

Amount expended in actual construction	$3,907,500.00
Interest charges, commissions, and amortization of capital	1,838,250.00
Total cost of reclamation	$5,745,750.00
Amount derived from sales of land, rents, etc.	3,907,000.00
Net cost to Government	$1,838,750.00

From these figures it appears that the net cost to the Government, after credits were deducted, was $42 per acre.

The average annual rainfall is 32 inches; the maximum 40.16 and the minimum 26.7. There are occasional instances on record when the rainfall for a single month was as much as 6 inches. The pumps are usually operated 94 days of 24 hours in a year, and when all are working they remove one-fourth to three-eighths inches of water in depth from the entire district in 24 hours. The annual tax for pumping and maintenance of the main ditches for some years after operations were begun was about 80 cents an acre.

Fig. 2 is a map of the Haarlem Lake area as it now exists, reproduced from the government topographical survey. About 16,000 people occupy this unique domain lying 12 feet below the level of the sea. Two towns in addition to the numerous farmsteads located along the main roads give an appearance of thrift and comfort to the entire area.

The drainage of Haarlem Lake was justly regarded as a great achievement. A period of fifteen years elapsed between the beginning and the consummation of the work, though it should be understood that a considerable part of that time was used in adjusting the rights

and claims of property owners outside of the lake. The sentiment which prevailed when the work was completed was forcibly expressed on a medal which was struck off by the Government. It is in Latin, but freely translated reads: "Haarlem Lake, after having for centuries assailed the surrounding fields to enlarge itself by their destruction, conquered at last by force of machinery, has returned to Holland its 44,280 acres of invaded land. The work commenced under William I, in 1839, and has been finished in 1853 under the reign of William III."

France and Italy. Both France and Italy can point to large drainage works by means of which the area of productive land has been increased. The project of La Gironde, France, included 1,500,000 acres, and of Forez, 140,000 acres. A notable one in the provinces of Mantua and Reggio, Italy, covering nearly 80,000 acres, cost $3,200,000, three-fifths of which was borne by the general Government, and the balance divided equally between the landowners and county governments. Italy depends for her cereal products as largely upon her drained areas as upon those which are irrigated. Several million acres have been made both sanitary and productive.

Field and Farm Drainage. We get, however, but a distorted view of the office which drainage has performed in agriculture if we confine our attention to the larger, and consequently more spectacular, projects of different countries. The control and conservation of water in all agricultural lands is an essential part of their management. They increase production without increasing the labor of tillage or extending the boundary of the field. Terracing and field drainage are becoming better understood, and their value appreciated in proportion as better methods of agriculture are practiced.

No greater incentive to the drainage of swamps or the protection of lands from overflow can be found than the results which follow the drainage of the field whose previous returns to its owner had been meager and uncertain. Field and farm drainage by means of the universal small open-ditch method has been largely supplemented and in many cases supplanted by the covered trench or underdrain. Trenches in which were placed stones or brush to serve as a water conduit and covered with earth were employed a hundred years before tile were known, and demonstrated conclusively, in many instances, that underdrains were superior to open ditches.

Use of Drain-Tile in Europe. The invention of clay tiles, or "land pipes," as they are called in England, for draining land, marks an important epoch in the history of drainage. Faure, in his work upon drainage, holds that the use of drain-tile originated in France, but credits England with the rediscovery of this method of draining which he concedes that France had lost. The discovery of drain-tile in the Convent garden at Maubeuge, in Northern France, in 1620, supports his claim. Drain-tile were first used in England on the estate of Sir James Graham, Northumberland, in 1810. They were made in two separate pieces, the top, called the "tile," being like the letter U inverted, and the sole, a flat plate upon which the tile was placed. These appear to have been the standard tile for thirty years. During this period the development of land drainage was slow. Quite indifferent success not infrequently attended the efforts of estate owners until 1840, when the experiments of Smith and of Parkes showed how tile-drainage would greatly increase the fertility of farm lands. The spread of underdraining throughout England and Scotland then became rapid. The action of

Parliament in 1846 creating a fund of $10,000,000 to be loaned to farmers, for use in draining their land, greatly promoted its development. In 1843 a machine was perfected for molding cylindrical tile which was enthusiastically welcomed by land drainers.

The movement which began in England extended to France and Germany, where equally salutary benefits followed the underdrainage of farm lands. According to figures collected by Mr. J. H. Klippart, about $8,000,000 were expended in France for draining from 1850 to 1856, and during the year 1856, 85,000 acres were thoroughly drained. It should be said in this connection that France and Germany have carried the art and science of underdrainage to greater perfection than any other countries.

Drain-Tile in the United States. The United States is indebted to England, or possibly, more accurately speaking, to Scotland, for her first lessons in tile-draining. John Johnston, a Scotchman, of Geneva, N. Y., known as the "Father of tile-drainage in the United States," introduced handmade drain-tile on his farm in 1835. By 1851 he had laid 16 miles of drains with most gratifying results. In 1848 the first drain-tile machine was imported from England, after which tile were obtained at a price which, as Mr. Johnston remarked, left a farmer without excuse for wet land.

The land which is now Central Park, New York City, consisting of 856 acres, which before improvement was regarded as a menace to the health of the city, was drained in 1858. At the time, it was the largest drainage work in this country, and as such attracted no little attention. Col. Geo. E. Waring, the engineer, copied English methods almost exclusively, using for lateral drains 1½-inch tile, with collars. His book, "Draining for Profit and for Health," published in 1867, quotes

the practice which was followed in the design and construction of that work.

Drainage in the South. The fact should not be overlooked that prior to these dates drainage by ditches and dikes was an essential feature of agriculture in the South. The culture of rice, which was exceedingly profitable along the tidal rivers, required the construction and maintenance of banks, ditches and sluices which entailed a large expense and watchful supervision, while many acres of level lands along the coast which were operated under the old plantation régime were provided with an elaborate network of ditches. No little enterprise was shown, particularly in the Carolinas, in developing the productiveness of those level but fertile lands. Had not this progress been interrupted by the war, the following years would doubtless have witnessed a great expansion in drainage operations.

The Westward Movement. Such were the beginnings of land drainage. They found the United States a vast and undeveloped country of unknown wealth and with agricultural possibilities which had not been dreamed of. The drainage movement, in common with other developments in agriculture, proceeded westward from New York into Ohio, Indiana and Illinois, and to a greater or less extent throughout the Middle West. The benefits of draining the fields and farms induced landowners to extend their operations so that the cooperation of many individuals was often required in the improvement of creeks and other natural watercourses, and also in constructing large artificial canals, which were required in draining large level areas. Drainage laws were enacted by the States, excavating machinery was perfected, numerous drain-tile factories were established, and, in short, a healthy activity in drainage character-

ized the half century following the introduction of modern methods in western New York.

The Present Outlook. By reason of the vastness of our country we have before us greater drainage problems and possibilities of land development than any nation in the world. More than 70,000,000 acres of unreclaimed land await the touch of the engineer and the intelligent activity of the ambitious and enterprising farmer, whenever they are ready to begin their reclamation. These lands are found in all parts of the country, and offer soils of every possible description. Besides these are the enclosed and cultivated lands, the production of no small part of which may be doubled by thorough drainage.

Government Aid and Encouragement. Legislative action in several instances has played an important part in promoting the reclamation of land. It cannot be denied that in the larger sense of the term the work is more or less a public function. We find that on this theory governments have participated in it by assisting in planning and directing the execution, and by advancing money in the form of loans on long time for the construction of the drains. England greatly encouraged drainage by passing the "Public Moneys Drainage Act" in 1846. It provided a sum of $10,000,000 for Great Britain and $5,000,000 for Ireland, to be loaned to owners for draining land, the work to be done under government supervision. The loan was to be repaid with interest in equal annual instalments, the time limit allowed being 22 years. In 1849 the "Private Moneys Drainage Act" was passed. This permitted the incorporation of land-improvement companies having authority to construct drainage works and loan money for this purpose, the amount to be secured by rentals from the land. A large amount of work was done under

these two acts in a systematic and thorough manner. France also authorized the loan of public money for draining, but it should be noted that in both countries the work proved so attractive in a few years that private enterprise rendered government loans unnecessary.

Belgium and Germany went so far as to establish factories and sell tile at low rates so as to place them within the reach of the majority of tenants and landowners. Experiments were conducted by these governments at various points so that all might be informed of the advantages of drainage. Assistance of this kind was given during the decade ending about 1856, since which time such work has been accomplished by individual enterprise, the governments becoming a party where the works were manifestly of public benefit.

Present Government Assistance. Government aid in England at present (1911) is limited to a law similar to the one passed in 1849. In France, the government through the Minister of Agriculture furnishes, upon request of landowners, engineers to lay out and superintend the construction of farm drains free of expense to the owners. The Province of Ontario, Canada, has a law giving the Province authority to loan farmers amounts to the limit of $1,000 each for expenditures in tile-draining; these to be repaid in 20 years at the rate of $7.36 annually on each $100 loaned. The provincial government also furnishes engineers to lay out farm drains with no cost to the owners except the traveling expenses of the engineer.

The United States Government has never granted specific loans to be applied in draining farm lands. Under the provisions of the Federal Farm Loan Act passed by Congress July 17, 1916, loans may be obtained by owners of farms, the proceeds of which may be used for making improvements, including farm

drainage, and for conducting farm operations more efficiently and profitably.

State Drainage Laws. To facilitate the construction of reclamation works of all classes, nearly every State has a general drainage law which gives landowners authority to effect drainage organizations of a cooperative character, levy and collect special assessments to defray the cost of the work and, if found expedient, to raise money by the issue of bonds secured by the lands which will be improved by the proposed work. Under the provisions of these statutes large and costly projects have been financed and the work successfully completed. Such laws provide the legal methods which have been found necessary for landowners to construct the larger drains and improvements, in which a considerable number have a common interest and consent to share the costs.

Advance in Methods. The development of methods of drainage is one of the most striking features of its history, particularly in our own country. The introduction of the land steam-dredging-machine in Illinois in 1885 was a noteworthy epoch in American drainage. The perfection of this type of machine made it practicable to open canals through the prairies and swamps and improve creeks effectively and at moderate cost. A variety of types of power land and floating excavating machines are in successful use for constructing large canals, and power trenching machines are employed for making underdrains. Dynamite assists in preparing the way for the machines through wooded lands, and its use for the actual digging of the ditches is being developed. Cement is at hand for drainage structures, while centrifugal pumps operated by steam, oil or gas engines lift the drainage water where gravity outlets are lacking, compressed air also being used under certain conditions

for the same purpose. Factories deliver clay and cement pipes for draining as large as 36 inches in diameter. These methods are in strong contrast with those which were employed half a century ago, and suggest further progress along these lines in the near future.

CHAPTER II

THE DRAINAGE ENGINEER

The magnitude of drainage operations which are called for today, the many phases of the work, and the economic as well as engineering problems which arise in the process of developing land, make the profession of drainage engineer one which requires special training and, if faithfully followed, involves no little responsibility, though yielding much of enjoyment and recompense.

The great variety of attainments which are demanded of the engineer will be apparent from a cursory view of the drainage field. It includes the drainage of fields and farms; plans for draining swamps and bodies of level land thousands and even millions of acres in extent; the improvement of watercourses; the protection of overflowed land by levee, and the diking of tidal marshes with the construction of the necessary ditches, sluices and pumping plants for such lands; the control of hillside waters; and the various problems relating to the drainage of irrigated lands.

Qualifications. The engineer should therefore have a quick eye for land surface and a good knowledge of soils, plants and agriculture in general, that he may detect differences in land by its topography and vegetable growth. He should be able to critically examine subsoil and other substrata and judge of their water properties, and should also be able to predict, in a measure at least, what effect draining will have upon lands and upon their value for agricultural purposes.

An examination of this kind should give him the information he needs for outlining such surveys as may be required. He should possess a full knowledge of technical engineering if he expects to handle all branches of drainage work. This of course carries with it proficiency in the use of level, transit and compass. He should be conversant with practical hydraulics, the details of levee building, pumping for drainage and up-to-date methods of construction. He should be able to present his work clearly, simply and logically by reports and maps, and discuss the various problems in a forceful and intelligent manner.

A part of the engineer's work is subject to the drainage law of the State in which it is done. To guard against any possible defects in his plans he should familiarize himself with the law so that he can make his surveys and reports conform to its requirements as far as legal procedure is concerned. He should be the adviser of drainage boards upon all points of design, and upon principles and methods of assessing damages and benefits. The latter subject deserves careful and analytical thought and should include an examination of such court decisions as have a bearing upon each case. The engineer should make himself invaluable to the board by elucidating the application of the law to the various conditions which are under consideration in such a manner that the members can intelligently come to an agreement in making the adjustments which the law requires of them.

An engineer should be a surveyor, but a surveyor is not by virtue of his occupation an engineer. The surveyor may make measurements, run levels and make maps but not be able to design an effective and economical drainage system. The engineer, however, cannot wisely direct such work unless he is himself proficient

in the details of surveying as well as in practical designing. In short, he should be able personally, if necessary, to do the work from the setting of the initial stake to the completion of the plans and estimates.

Association with Public Boards. The drainage engineer is called upon to deal with corporations, boards of commissioners and drainage associations, as well as with individuals, in his capacity of professional expert and counselor. He has facts and professional knowledge which they do not possess. He should make his employers' case his own and give them the best plans and advice at his command, having due regard to sound practice and enduring results. He should be able to divest his reports of technical details to such a degree that his clients will understand the subject under consideration clearly and be able to act intelligently upon the proposition. It is an element of weakness on the part of the engineer to obscure his work by technicalities which he does not expect the layman to understand. Drainage is a simple, common-sense operation, the plans for which can be made intelligible to any attentive mind.

The engineer is sometimes urged to modify his plans and recommendations and endorse methods which in his judgment are not wise, and often heavy pressure is brought to bear upon him from various sources in order to bring this about. Possibly changes may be made without injury, but they should be carefully reviewed and if they are found impracticable and ill-advised, the engineer should so represent them. It should be remembered that the board or company expects reliable advice from the engineer and will be ready to censure him even for compliance with their wishes if he endorses a plan which, in the end, proves unsatisfactory or fails entirely. He should not be a tool in the hands of the board or any interested party, but an honest counselor

and director of the undertaking for which he has been employed. His plans should possess such merit that they will appeal to his clients and any differences of opinion or judgment should be courteously discussed. Such a course calls for the exercise of a high order of common-sense, good judgment and integrity in addition to the technical skill required in the management of the project which has been intrusted to him.

Professional Enthusiasm. He should not let his ideas of engineering precision lead him to do work which will have little practical value in dealing with the project he is working out, yet he should conduct his work in a professional way and with due regard to conventional accuracy. He should honor his profession by exhibiting a well-balanced enthusiasm in all of its branches, and by ability and trustworthiness establish himself in the confidence of all with whom he has professional or business relations. Since he comes in contact with people of diverse opinions and temperaments to whom he is expected to explain his plans and to instruct in affairs relating to drainage, it becomes him to cultivate patience, courtesy and a sympathetic personality.

Notable European Drainage Engineers. The American engineer who proposes to devote his time and talents to drainage work is following in the wake of engineers of the Old World of no mean ability and reputation. With the reclamation of the English Fens, before referred to, are associated the names of such engineers as Cornelius Vermuiden, whose early achievements in Holland drainage work led to his employment in the time of King Charles the First, and who in 1642 reported to the King a plan for controlling the waters of the rivers which crossed the fens, and who was later identified with various improvements in fen drainage. Sir William Dugdale was connected with some of the

earlier works. His book upon the History of Draining and Embanking contains the most complete record extant of the early attempts to drain the fens. Thomas Telford, whose name is associated with road building, Sir John Rennie, who was knighted by the Crown in appreciation of services on the great London bridge, and Sir John Hawkshaw, all noted engineers, made examinations and reports on various problems connected with fen drainage. W. H. Wheeler, whose excellent works on the "Drainage of Fens and Lowlands" and "History of the Fens of South Lincolnshire" are invaluable additions to drainage literature, was connected with later developments of English lowlands.

Among those who were later identified with the drainage of the uplands of England and Scotland should be mentioned Josiah Parkes, consulting engineer for the Royal Agricultural Society, and J. Bailey Denton, member of the Institution of Civil Engineers of England. The long career of the latter in directing farm-drainage operations, together with his able expositions of the theory and practice of such work, justly entitles him to the esteem which is accorded him by the English people.

To this incomplete list of English drainage engineers might be added the names of many equally eminent in almost every country of Europe, notably France, Belgium, Germany and Italy, all of whom have by their engineering skill in the design and direction of large drainage undertakings exerted a marked and beneficent influence upon agricultural development in their respective countries.

It may not be out of place to mention here that unique character, Joseph Elkington, of Warwickshire, England, who, though an illiterate farmer without training of any kind, left his indelible stamp upon drainage practice.

He first discovered and applied a new method of draining to his own farm in 1764 and soon became noted for his skill in draining lands which were similar in character. His discovery and successful practice created such interest in the agricultural circles of England and Scotland that Parliament in 1795 voted him £1000 in appreciation of his services. Briefly described, his method consisted in seeking out hidden springs and water currents and tapping them by means of auger holes which were made in the bottom of deep ditches. The water being under pressure rose in the holes and flowed away in the ditches. Elkington possessed the gift of locating underground sources of water and succeeded in drying bogs which resulted from seepage from higher lands and from the flow of hidden springs. The system which is known by his name is now successfully applied in draining irrigated lands in the West.

The successful career of Elkington emphasizes one important qualification of the drainage engineer which does not come from college training nor is it acquired from books. It is the ability to determine the source of the trouble. This is in some degree a natural gift, but may be to a large extent acquired by close observation and practical experience in investigation of soils under varying conditions. Though without book-learning, Elkington possessed the practical skill which enabled him to read soils.

Opportunities for Professional Improvement. The American engineer has been compelled to modify European practice quite materially to meet the requirements of this country. Our soil and climate are peculiar to America. Our areas to be treated are large and their possibilities are attracting the attention of owners and investors. We need but point to the mistakes that have been made during the last 25 years to show that

the field demands the best talent which the profession can give. It is urged that engineers who lack experience, be they young or old, associate themselves for a time with some one of experience before assuming the responsibility of designing a system of drainage. In any event, the subject should be studied on the ground with a care commensurate with the importance of the undertaking.

It need hardly be suggested that the engineer should be a close student not only of science and nature, but of practical affairs as well. He may also with profit frequently systematize his methods of work and direct his thinking along logical lines by contributing to the columns of technical and popular periodicals. The art of expressing thought in terse and clear English and of arranging subjects in a logical and orderly way is exceedingly valuable to the engineer and should form a part of his professional training and career, as should public speaking also, since he will frequently be called upon to address gatherings of engineers or agriculturists in the interests of drainage, and it will be a serious handicap if unable to do so readily and well.

Land drainage is an enterprise of such nature that a drainage engineer may justly take pride in the fact that his labors contribute materially not only to the wealth and prosperity of the community and the country at large, but also to the comfort and health of the people and the beautifying of their homes, while the permanency of drainage works makes them an enduring monument to his skill.

CHAPTER III

ENGINEERING TECHNIQUE

DRAINAGE engineering, in common with other branches of civil-engineering, demands mechanical skill in the use of such instruments as are necessary in field or office work. While the professional engineer in any branch should wholly master what may be called the technique of his profession, including a perfect familiarity with all forms of instruments employed in the work, and skill and dexterity in the various methods of using them to secure the data sought, the subject will be briefly presented here, covering only the simplest and most important points, with the expectation that the engineer will constantly add to his knowledge and proficiency, both by experience and by information gathered from books and other sources.

Field-Work Equipment. Instrument-work in the field is required to secure the facts regarding surface levels, depth and size of watercourses utilized, location of property lines, and other data which the engineer will need in ascertaining the conditions existing, in planning the system of drainage demanded, and later, in laying out and constructing the work as planned. The equipment for field-work need not be large, but should be well selected. An instrument which is susceptible of more general use than any other is the engineer's combined level and transit. This should be furnished with a sensitive and well-set telescope level, stadia hairs set to cover one foot on the rod at a distance of 100 feet, plus

a constant, a compass with variation plate, and a vertical arc, or half circle, for measuring vertical angles. Excellent leveling can be done with such an instrument, and by using the vernier plates, compass and stadia, every variety of instrument-work required in making drainage surveys can be performed.

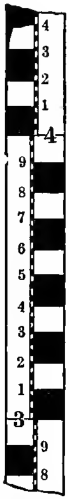


Fig. 3.—Folding Self-reading Rod.

The 18-inch Y level, equipped with stadia hairs and a detachable strident 3-inch compass upon the telescope, is also an instrument of almost general use in making drainage surveys upon level lands.

The ordinary target-rod is quite essential in checking benches and in primary leveling, but the "speaking," or self-reading rod, is the better for general use, as it can be employed for both level and stadia work. When graduated properly it can be read with distinctness by the instrument-man, thereby making him independent of the rodman, besides enabling him to work more expeditiously. A great many designs of such rods are in use. The style of graduation that the author has found most easily and accurately read is represented by **Fig. 3.** This is made of a strip of straight-grained white pine, 1 inch thick, 2½ inches wide and 12 feet long. The ends are shod with bands of iron ⅛-inch thick to protect them from battering. The rod is cut in two in the middle and a plain strap hinge set in even with the face so that the faces of the two parts can be folded together for convenience in transportation. It is held open while in use by means of a rib of wood which is fastened to the back by screws and covers the joint. A movable bolt with a thumb-nut is used to fasten the rod open or shut as desired. The dark spaces in the figure, showing tenths

of a foot, are red on the rod. The foot figures are large and painted red. The tenths figures are black, and the small squares along the center line representing two-hundredths spaces, are also black. The arrangement of spaces and colors is such as to be clearly read at a distance of five hundred to eight hundred feet, depending upon the power of the telescope and the strength of the light.

Fig. 4 represents a 14-foot non-folding rod which is a favorite with engineers. It is made of straight-grained white pine 4 inches wide, ⅞-inch thick, with a rib on the back to give greater stiffness, the ends being capped with straps of iron ⅛-inch thick. It is painted white and black as shown in the cut, the divisions being half-tenths of a foot. It is a superior stadia rod which can be made cheaply, and is durable if covered with first-class enamel paint.

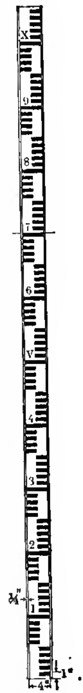


FIG. 4.—STADIA AND LEVEL-ROD.

The 100-foot steel wire chain with brazed links is, perhaps, the most convenient and serviceable for use in drainage surveys through a rough country, but is open to the objection that the links wear rapidly so that the chain requires frequent correction. The band chain, or steel tape, should be kept on hand as a standard by which to correct the chain and also for checking the stadia distances, but its liability to be broken in the hands of workmen, as well as the disadvantage in its use of requiring two hands for setting a pin at the fore end, makes it less desirable for constant use than the chain. A set of eleven marking pins should accompany the chain. Two or more flag-poles, steel or iron pointed, and each bearing a flag of cloth 8 in. by 12 in.,

half white and half red, are needed in marking out courses for chainmen and axmen to follow when staking out lines. Machetes, or long heavy knives with handles, are best for cutting brush; these, with shoulder sacks for carrying stakes and hand-axes for driving them, may complete the engineer's instrument outfit for field-work.

Leveling. Leveling is the fundamental and most important instrument-work connected with drainage engineering. While the operation is simple, it is easy for the instrument-man to make a mistake which will render the entire work valueless until the mistake can

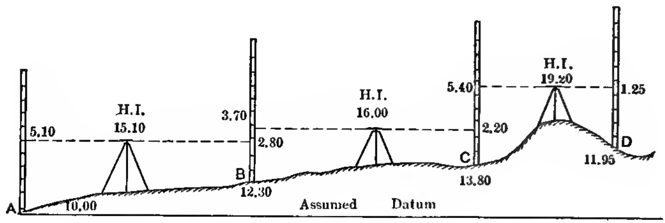


FIG. 5.—LEVELING.

be found and corrected. For this reason he should be careful to keep his level in perfect adjustment, and use a method of keeping notes which will apply to all situations, since following the same routine establishes a habit of work which is conducive to accuracy. The notes can hardly be too complete or too carefully kept. In the words of an old professor, "Always put your notes down as if you expected to die before morning, and wanted to leave them in such good condition that in ten years' time, a stranger, with none of the old party to help him, could take your book and proceed on the job without delay." A method of checking work in the field should also become a habit of the level-man.

A convenient size for a field-book is 4 inches by 6½

inches, containing 160 pages. Two pages facing each other are required for each set of notes, the left-hand page being ruled in five columns and headed as shown below, the right-hand being open for explanations, sketches, etc.

LEVEL-NOTES TO ACCOMPANY FIG. 5.

Sta	B S	H I	F S	Elev
A	5.10	15.10	....	10.00
B	3.70	16.00	2.80	12.30
C	5.40	19.20	2.20	13.80
D	....	....	4.25	14.95

To run a level-line, select some bench-mark or other permanent point from which it is proposed to start and establish a datum to which all levels in that survey shall be referred. If its elevation is not known, assume one which will be convenient to use without introducing minus expressions. If we begin low down on some watercourse perhaps 10.00 will do; if higher up 20.00, 30.00 or 100.00 should be used as the elevation of the starting point. If some permanent railroad or government bench with recorded elevation is within reach utilize it. Place this in the elevation column opposite Sta A (**See Fig. 5 and accompanying notes**). Set the level midway between this point and the next point **B**, or, if more convenient, on one side of the line, provided the distance from the position of the level to either point is about equal. Have the rodman hold the rod vertically at **A**, and with the level-bubble in the center, read the rod at the point where the horizontal cross-hair intersects it. This is called a backsight, and in the example is 5:10. Enter this in the B S column opposite Sta A; add the backsight to the elevation of the point **A**, thus obtaining

the elevation of the line of sight through the instrument, or the height of instrument, as it is called, abbreviated on the notes to H I. In this case it is 15.10, and is entered in the H I column opposite Sta A. Next take a sight in a similar manner on B, called a foresight, and enter the reading in the F S column opposite Sta B. This in the example is 2.80. Subtract this reading from 15.10, in the H I column, and write the difference, 12.30, in the Elev column opposite Sta B. This is the height of B with reference to A. If the elevation of other points is desired before the instrument is moved, take as many foresights as wanted and obtain the elevation of the points by subtracting each from the H I. Next move the instrument to some point beyond B and take a backsight on B. Record it in the B S column opposite Sta B and add it to the elevation of B to obtain the H I in its new position. Enter the sum in the H I column opposite Sta B. In the example the B S is 3.70, Elev 12.30 and H I 16.00. Take a foresight on C, subtract the reading from 16.00, the H I, and obtain 13.80, the elevation of C. Remove the instrument to a point beyond C and obtain the elevation of D in the same way. The points upon which two readings are taken are called turning-points. All others, except bench-marks, are called intermediates. Pegs should be driven into the ground upon which to make turning-points, if more permanent ones are not at hand. This method of procedure is simple and can be universally applied.

The work in the field can be "checked," or proved, by re-running the line in an opposite direction, and also by occasional long backsights to stations already leveled, the results of which will indicate whether any serious error has been made.

The book may be checked, first, by reviewing the additions and subtractions carefully and, second, by

finding if the difference between the sum of the foresights and the sum of the backsights is the same as the difference in the elevation of the points compared. In the example just examined:

Elev D =	14.95	Sum of backsights =	14.20
" A =	10.00	" " foresights =	9.25
Difference	4.95	Difference	4.95

Stadia Work. The stadia is particularly useful for measuring distances, and is more accurate for that purpose than chaining as ordinarily done. The distance is found by observing what portion of the image of the graduated rod is included between the cross-hairs of the telescope. The farther the rod is from the instrument the greater is the portion of the image which falls between the cross-hairs. The hairs, one on each side of the center, are so placed that they include one foot on the rod at a distance of 100 feet, two feet at a distance of 200 feet, and so on as far as the rod can be read, proportionate spaces included on the rod representing proportionate distances. The distance read is not from the center of the instrument but from a point in front of the center equal to the focal length of the telescope. This length, called a constant, determined by the maker and furnished with each instrument, must be added to each distance-reading to obtain the distance from center of instrument to the rod. The rod should be held vertical to the line of sight, which is easily done on level land. The use of the level-rod for stadia purposes enables the engineer to locate a point by azimuth, distance and elevation at one operation.

Compass Work. The magnetic compass, placed either upon the engineer's transit or upon the telescope of the level, as before described, is exceedingly serviceable in making drainage surveys, and gives more accurate results

than are usually attributed to it. In fact, for locating "stadia shots" and in running out drain lines or locating points for various purposes after a permanent base of operations has been established to which such lines may be referred and checked, and particularly for use in a wooded or brushy country, the compass meets every requirement. It should, however, be employed for running short lines only, and where slight errors will be of no material importance.

The needle indicates the magnetic meridian, an approximately north and south line. The true meridian is a north and south line which if extended would pass through the north pole of the earth.

The compass circle is divided into degrees and fractions of a degree. The letter E, denoting east, is at the left hand, and W, west, at the right hand of the box, which is contrary to the position of these letters in the small pocket-compasses. This arrangement is necessary because in using the field-compass the box is turned so that the sights point in the direction of the line whose azimuth is to be obtained. The north end of the needle is read, which gives direct the azimuth of the line, or the angle which it makes with the magnetic meridian.

The bearing of a line is the angle which it makes with the direction of the magnetic needle. The length of a line, with its bearing, is termed its course. To take the bearings of a line, set the compass directly over a point in it, at one extremity, if possible, though this is not essential. Bring the compass to a level position. Have a flag or rod set on another point of the line. Direct the sights upon this rod as near the bottom as possible. Always keep the north end of the compass ahead. It is distinguished from the south end by some conspicuous mark on the face. Sight accurately to the flag and read the north end of the needle. To do this, note first the

N. or S. point of the compass, according to which is nearest the north end of the needle; second, the number of degrees to which it points; third, the letter E. or W., whichever is nearest the north end of the needle. Always read and record bearings in this order. To illustrate: In Fig. 6, a b is the line along which the sights point.

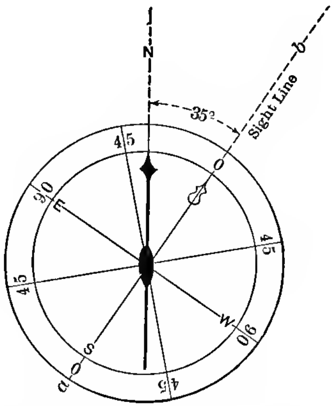


FIG. 6.—TAKING COMPASS BEARINGS.

The needle points constantly to the meridian, hence in turning the sights to the line a b, the angle N b is turned off, or from 0° to 35°, and the needle reads north, 35° east, hence the bearing of the line is N. 35° E. To test the accuracy of the bearing, set up the instrument at the opposite end of the line and take a backsight upon the first point. If the number of degrees read the same but with opposite letters, the bearing first taken was correct.

The declination of the needle is the angle which the magnetic meridian and the true meridian make with each other, and though constantly changing it must always be taken into account except on or near a certain line

passing across the country called "the line of no variation." While this line, of course, varies slightly with the changes in declination, it enters the U. S. near the eastern end of Lake Superior and passes in a southeasterly direction through Michigan, Ohio, etc., leaving the U. S. at a point on the coast of South Carolina, below Charleston.

It is desirable to record lines with their true bearings, or as nearly so as practicable, though this feature of the work is not so important in drainage surveys as in those which are made for the definition and determination of land-lines. The local declination can be determined by setting up the compass upon an old land-line whose bearing is known, if such can be found, or in the absence of such a line, a bearing may be taken upon the pole-star and declination noted. This will be only approximate, as the star is 1½ degrees from the pole, revolving about it, and is on the true meridian only twice in twenty-four hours.

Another method of determining an approximately true meridian is by equal shadows cast by the sun. At some point on a level surface, as at **s** in **Fig. 7**, place an upright staff not less than 10 feet long. Two or three hours before noon mark the extremity of its shadow, as **a**. Describe an arc of a circle with s, the foot of the staff for center, and **s a**, the distance to the extremity of the shadow for radius. Shortly before the length of time after noon that it was before noon when the first mark was made, watch the shadow, and when its end touches the arc previously described mark the point, as **b**. Bisect the arc **a b** and mark the point **n**. Then **s n** will be the true north and south line. Set up the compass at s, sight on **n** or **s n** produced, and read the needle at that place.

It is more important, however, to record on the notes

the declination used than it is to go into the niceties of obtaining and using an absolutely correct declination angle for line work of the character herein described. If the compass has a declination plate, set off the declination assumed or determined, and record all bearings as read. If there is no such provision for mechanically correcting the azimuth make corrections on the notes according to the following rule: When the variation is east, as in localities west or southwest of the line of no variation, for bearings N. and W. or S. and E. subtract

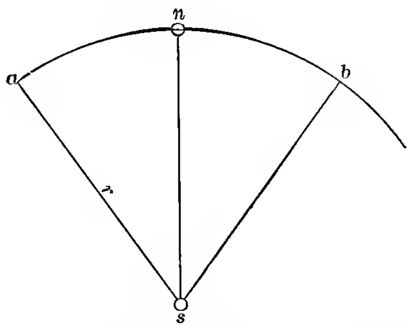


FIG. 7.—OBTAINING MERIDIAN BY EQUAL SHADOWS.

declination from magnetic bearing. For bearings N. and E. or S. and W. add instead of subtract.

When the variation is west, as in localities east and northeast of the line of no variation, for bearings N. and W. or S. and E. add the declination, and for bearings N. and E. or S. and W. subtract. Care must be taken that wire fences or other improvements of iron or steel are not near enough to the compass to deflect the needle and give an inaccurate reading. If necessary to obtain the bearing of a wire fence line, an offset of 30 feet may be made, and the bearing of this parallel line be read.

Keeping Compass Notes. The running form of keeping notes is simple and in common use. For example, in recording the notes of drains, the following notes may be written on the right-hand page of the level-book.

DRAIN NO. 2

Sta 0– 6	N 10° 30′ E
Sta 6– 8	N 4° 00′ E
Sta 8–15	N 32° 00′ W
Sta 15–22 (end)	N 15° 20′ W

The same form should be used to record a continuous and connected line like the boundary of a farm or field.

Backsights should be taken at each station to ascertain if there are any disturbing influences which cause the needle to read differently at the two ends of the line. If a discrepancy in the two readings is found, some point on the same line intermediate between the two should be used to determine which of the bearings is correct.

Location of Stadia Points. For locating the position of stadia points by the transit with attached compass and obtaining their elevations at the same time, use the following method: Set the instrument over a station whose elevation is known and add the distance between the hub of the station and the center of the telescope to the elevation of the station, to obtain the height of instrument (H I). Take sights at the rod as it is held at selected points within the range of the observing station. Read the interval on the rod subtended by the stadia hairs for distance, read the position of the center hair upon the rod, when the level bubble is centered, to

obtain elevation, and read the north end of the needle for azimuth or direction. Record the readings and results in the following form:

OBSERVATIONS AT STA 4

Elev 127.02 H I 132.42 Stadia Constant 1.31

Point	Stadia Rd'g	Distance, Ft.	Bearing	F S	Elev
1	6.21 2.32	389	N 89° W	4.32	128.10
2	7.10 2.15	495	N 46° 30′ W	2.41	130.01
3	8.41 2.41	600	N 44° W	3.21	129.21

NOTE.—Add the stadia constant, 1.31 ft., to each distance reading.

Survey for Contour-Lines. Contour-lines are drawn upon a map connecting points on the surface of the land having the same elevation. The vertical distances between the lines may be any chosen length, as 2 feet or 5 feet, but are equal on the same map. A number on each line indicates the elevation of the ground at the points on that line which were read, and, assumedly, between them. The slope of the land is at right angles to the contour-lines, being steepest where the lines are closest together and nearest level where they are farthest apart. It is sometimes desirable to delineate the surface-slopes in this way as a base for representing permanently the relation of slopes of various fields to each other and to improvements which it may be desired to establish from time to time. Taken in connection with

physical land conditions it becomes useful in planning drainage systems.

There are two methods of survey for representing contour-lines, but the one deserving first mention is **the transit and stadia method.** Run a base-line through the tract, setting permanent hubs by chain and transit 1,000 feet apart, or less if the land is obstructed by trees and brush, and find the elevation of each. These are stations from which to make measurements with the transit and stadia rod. The base-line need not be a straight line through the entire tract, but may be deflected to conform with the shape of the area to be examined. Set the transit over each of the stations, the height of the instrument being obtained by adding the height which the telescope stands above the station to the elevation of the station. The rodman then selects the point and the instrument-man reads the distance to the point by the stadia, and also reads the position of the center hair upon the rod to obtain the elevation. In addition, he reads upon the limb of the transit the angle which the line makes with the base-line, or, in case the compass is used, he reads the bearing of the line by the needle. If the surface has but little slope and is uniform, but few points need be located. Side base-lines may be run out from the primary one if necessary to reach other parts of the tract.

At the close of the field-work the base-line should be plotted to a convenient scale and points located on it by scale and protractor, and the elevations recorded at each point on the map. Contour-lines may then be sketched in to represent such vertical distances as may be desired. The lines will, of course, be interpolated between points on the assumption that the slope is uniform between the points recorded.

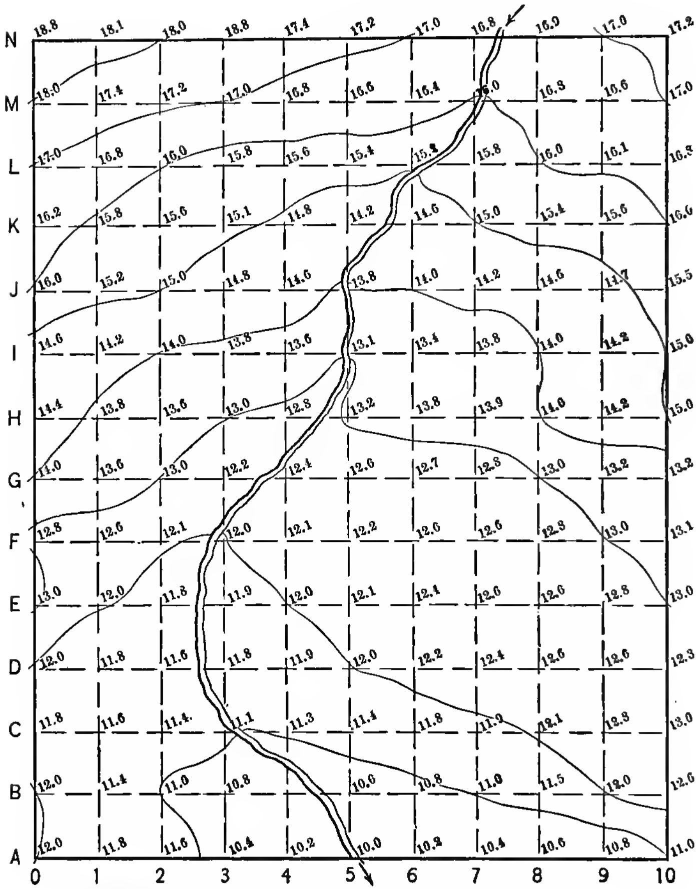
The second is **the level and chain method,** and re-

quires that the land first be laid off in 100-feet squares. Begin at one corner of the farm or tract whose adjacent sides are straight lines and use them as bases from which to work. Have stakes prepared about 16 inches long. Begin at the corner and measure off a base, setting a stake at each station of 100 feet, lettering the stakes A, B, C, etc., in order. Begin at the point A and measure from that point along the adjacent side in the same manner, numbering the stations 1, 2, 3, etc., until the limit of the field is reached.

Set a flag-pole 100 feet from the last stake at a right angle to the last line run. Begin at stake B on the base-line and run to the flag, setting stakes at each 100 feet, numbering them B 1, B 2, B 3, etc. Proceed in the same manner across the entire farm until it is checked into squares of 100 feet. The lines are described by letters, and any point on the lines by the number of the stake, as B 5, D 26, etc.

Before beginning the level-work, establish a bench-mark and assume a datum-plane at the initial point, or A, of the base-line. Following the lines A, B, C, etc., take levels at each of the stakes, heading the level-book pages "Levels on Line A," "Levels on Line B," etc. Two lines may be leveled at one passage. "Turning-points" should be taken on pegs, but other levels may be taken on the ground.

Make a plat of the area upon a scale which should be governed by the use which is to be made of the map. One-half inch to 100 feet is a convenient scale for a farm of 160 acres. Reproduce the lines laid off in the field so that the plat will correctly represent the field on the scale adopted. (Fig. 8.) Write the elevations which are recorded in the field-book at the intersections of the lines on the plat, which intersections represent the position of the stakes in the field. Con-



Squares=100 feet Level Datum=10 ft. Rise between Contours=1 ft.

FIG. 8.—TOPOGRAPHY BY CONTOURS.

tours may now be sketched in to represent any vertical distance desired. Each contour should be numbered with its proper elevation in feet so that any one inspecting the map can read at a glance the elevation of any part of the tract. The contours are but the graphical representation of the elevations. Any natural features, such as ditches, streams or clumps of trees should be added, as also roads and buildings.

Office Equipment. An important part of the engineer's work is done in the office in order that permanent records may be kept of all important facts pertaining to each project. When extended surveys are made, the data recorded in the field-books must be represented by maps, profiles and sectional drawings, and in such a manner as to reflect credit upon the engineer, for while roughly prepared drawings will represent the work, provided they are correct and contain all the information needed, the demand for neat and attractive drawings, with orderly, well-prepared estimate sheets and reports is such that no engineer can afford to disregard it. However proficient he may be in preparing drawings when surrounded with the outfit of a well-furnished office, he should also be able to make good working drawings with a few instruments at field headquarters. The equipment for such work need be only a small drawing-board, a straight-edge, two triangles, a decimal scale, a right-line pen, a bow-pen, a protractor, writing pens, black and red drafting inks, thumb-tacks and drawing paper. With these he should be able to turn out creditable working plans for small projects with reasonable dispatch and accuracy. The permanent office room should be furnished with a heavy drawing-board, 4 feet by 6 feet, placed on strong trusses, and in addition to the articles previously named there should be a long T square, a half-dozen cakes of water

colors with saucers and brushes, a full supply of drawing, profile and tracing paper, and a case for filing drawings. He may add many other desirable things, but these constitute the necessities for drafting.

A slide-rule is a great time-saver in computations, and the engineer should be proficient in its use.

Preparation of Maps. Maps are made to represent or record the facts which have been obtained by the survey and also to show clearly such drainage plans as have been developed from the results of the survey. (Fig. 9.) The scale upon which the map is to be made must be first decided. It is always desirable to represent the entire work upon one sheet, yet the map should be of a size convenient for use. If the area of the project is large, several sheets may be used, and when placed together temporarily, they will represent the entire project as a unit. The scale should be suited to the amount of matter which the engineer proposes to put upon the map. For farm drainage maps, a scale of 1 inch to 200 feet will be large enough and sometimes 1 inch to 300 feet will serve every purpose. For large districts a scale 2 inches to 4 inches per mile will meet the requirements. It should be remembered that the map is made for the information of those who may or may not be acquainted with the ground. The meaning of every figure or symbol should be clearly expressed somewhere upon the map. Topographical symbols should be used somewhat sparingly, otherwise they may take the place of information that should be expressed in words. Elevation figures are always in order and should be used freely on the map, not neglecting to describe the datum upon which they are based.

The appearance and clearness of a drainage map may be enhanced by the use of conventional colors. All natural and permanent features as land-lines, roads,

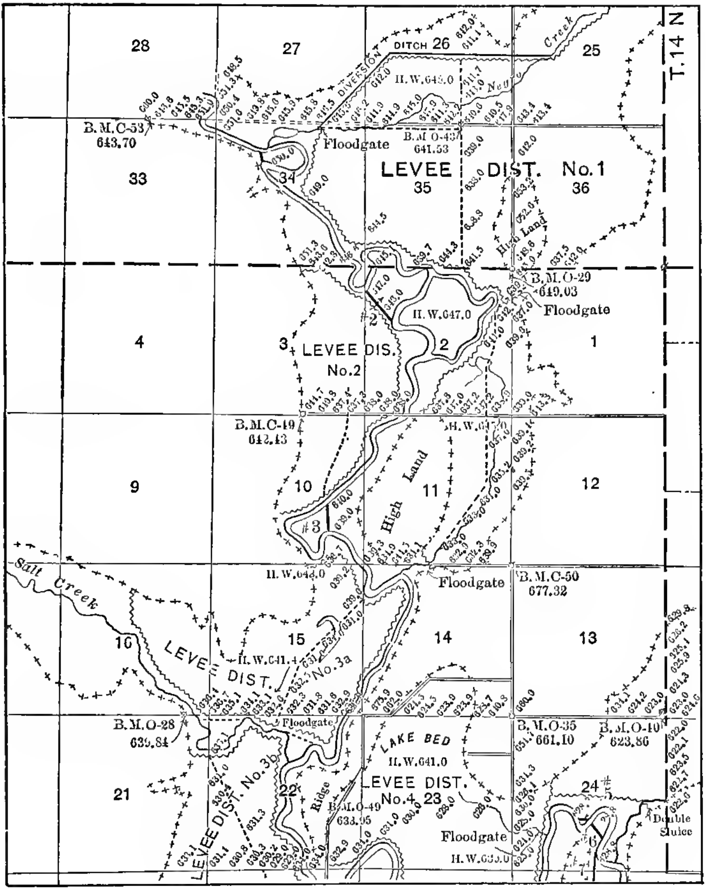


FIG. 9—PORTION OF MAP OF LEVEE DISTRICTS.
From files of Drainage Investigations U. S. Dept. of Agriculture.

trees, etc., should be represented in black; bodies of water, as lakes, rivers, and ponds by light tint of blue, the border being a free-hand black line; watershed boundary lines should be indicated by a heavy dotted or barred line touched with a light shade of chrome yellow; contour-lines should be drawn in lightly with sepia brown. All proposed drains and figures that go with them on the map should be drawn in red. The position of bench-marks and their elevation should be recorded on the map.

The lettering should be mainly the straight stroke, free-hand style, varied in size and thickness of line to give a pleasing effect as one views the map. Neatness and dispatch should be the aim in this part of the execution.

The title should be in keeping with the general appearance of the drawing, though some embellishment is permissible. It should state concisely what the map represents and what it is made for, these being shown prominently in the design. It should bear the name of the engineer and the date upon which the field-work was done. Near the title, though not a part of it, should appear the line-scale to which the map is drawn, the legend of such symbols as may require explanation, and an arrow to indicate the north and south directions. The map should be completed by a heavy border-line. Work with a hard pencil and make changes until everything is as desired, after which the lines should be "inked in." Illustrative designs for title are shown in Figs. 10 and 11.

Plotting Angles and Locating Points. Drawing on paper the lines and angles which have been measured on the ground constitutes **plotting the survey.** The lines should be drawn to the scale which has been adopted, and the angles laid off with the protractor.

To lay off an angle, place the straight edge of the protractor on the line from which the angle is to be measured, and the center mark of the protractor on the point of the line from which the deflection is made; with the point of a sharp pencil make a dot on the paper at the required number of degrees and draw a line from the

MAP OF

THE DEEP FORK OF CANADIAN RIVER

OKMULGEE COUNTY, OKLAHOMA.

Showing proposed Levees and Cut-offs on Main Stream and Diversion Ditches and Levees on Tributaries.

Designed to relieve the bottom lands from overflow.

SURVEYED AUG.-SEPT 1909

SCALE: 2 IN. = 1 MILE

____________ *Chief of Party*

____________ *Engineer in Charge*

LEGEND

Proposed Ditches & Cut-offs		*Surface Elevations*	609.7 605.9 637.1 613.9
Located Relief Ditches		*Bench Marks*	B. M. O-39 630.94
Proposed Levees		*Railroads*	
Meandered Bluff Line		*Bridges*	

NOTE.—The scale of working maps and drawings is usually indicated as above, but a line-scale showing length of distance units is preferable since in reduction of maps by photography the latter is proportionately reduced, while the former will be no longer correct.

FIG. 10.—TITLE OF MAP OF LEVEE DISTRICTS.

station-point through the angle-point; with the scale lay off on this line the distance as recorded in the notes for that station. If the level-notes show an elevation for that point record it upon the map.

To plot compass-notes, draw a meridian line in light pencil through the initial station or any point from

which magnetic bearings have been taken, place the protractor upon the line and point, as directed in the preceding paragraph and lay off the angle called for by the notes. Set off by scale the distance on this course to the next point. Draw a meridian line through the

MAP OF

BERRY SCHOOL FARM

ROME, FLOYD COUNTY

GEORGIA

Showing proposed tile drains and sewerage system.
Prepared to accompany a report on proposed improvements

SURVEYED IN 1908
by
———— *Drainage Engineer*

SCALE: 1 INCH=200 FT.

LEGEND

———— Proposed tile drains
- - - - - - Boundary of field
-x-x-x- Fence
— - — -- Proposed sewer
▬▬▬ Open ditches
O Catch Basins
1 Recitation Hall
2 Brewster Hall
3 Rheo Cottage
4 Cabin
5 Hospital
6 Inman Hall
7 Poland Hall
8 Cherokee Lodge
9 Laundry
10 Shop
11 Woodshed
Buildings, fences and roads, approximately located

FIG. 11.—TITLE OF FARM DRAINAGE MAP.

point thus established and in the same manner plot the following courses. Should a field have been surveyed, the last course ending at the starting-point, the lines should meet, or close. If the line does not close

it shows that some error has been made either in the field or in plotting the notes. The method of using the protractor in plotting compass-notes is shown in **Fig. 12.** The semicircle part of the protractor should be placed in the direction of the course to be marked, and the angle

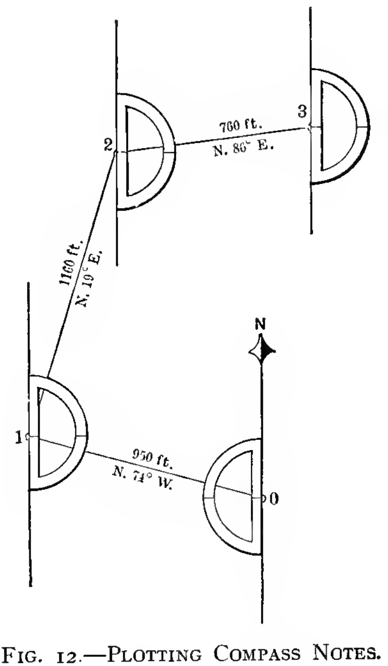


FIG. 12.—PLOTTING COMPASS NOTES.

read from the north end of the protractor for all bearings beginning with **N** and from the south end for bearings beginning with **S**.

Conventional Topographic Signs. These are representations of the more prominent features of the land by arbitrary signs, based upon the appearance of the objects in horizontal projection. Those commonly used

on drainage maps are shown in **Fig. 13.** A sufficient number of symbols should be employed to show at a glance what the character of the surface is, but, as before suggested, they should not be used to the exclusion of descriptive words, especially when, as frequently happens in drainage work, the maps will be examined by interested parties who are unfamiliar with the conventional signs.

Profiles. Profiles are employed to show graphically the relation of the surface to the grade and depth of a channel or drain, and are prepared to accompany a map upon which is shown a plan of drainage. Profile-paper, as furnished by supply stores, is ruled so that no other scale is required in plotting. The vertical scale for a unit of distance is very much greater than the horizontal in order that the vertical distances may be accurately represented. The paper may be had in translucent form from which blue-prints can be made.

The surface-line as taken from the level-notes should be plotted to the scale adopted, the position of the points being marked by a dot of the pencil and afterward connected by a line. (See **Fig. 21, Chap. VI.**) This work should be carefully checked. The grade of the channel should then be drawn, after which the cut or depth at any point along the line can be read by scale.

The title should state in plain, free-hand lettering what line the profile represents and what map or report it is to accompany. The distances represented by the spaces on the paper, both horizontal and vertical, should be explained in a note.

Copying Maps. It is usually necessary to make copies of maps and profiles for various purposes connected with the design and construction of drainage work. This is done by stretching tracing-cloth, or vellum, over the original map and tracing the lines upon

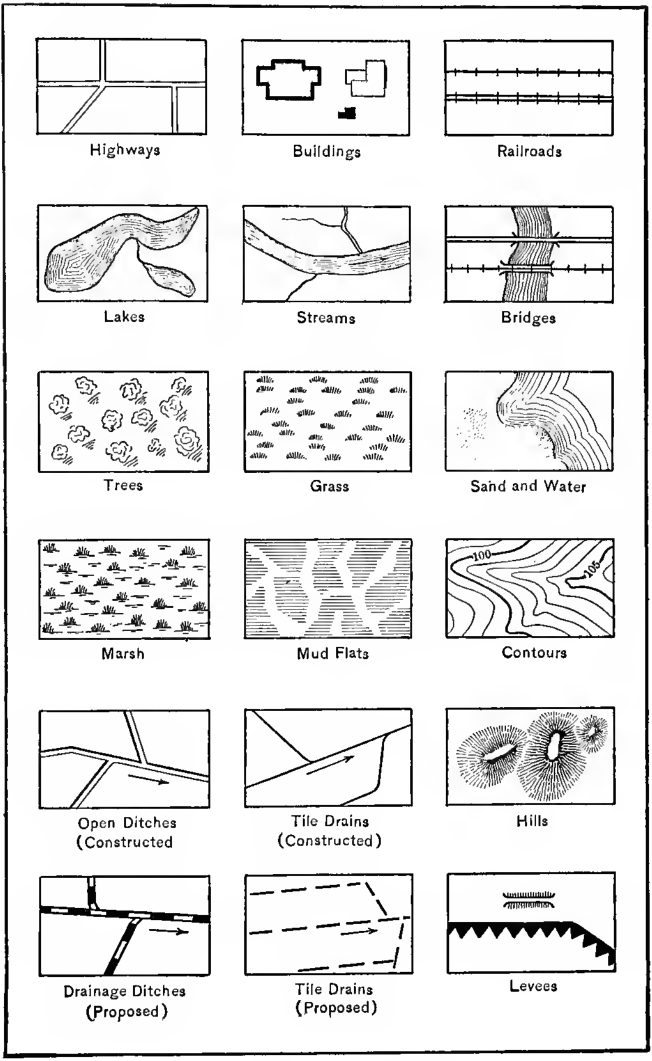


FIG. 13.—CONVENTIONAL TOPOGRAPHIC SIGNS.

the cloth with ink. This tracing is then used as a negative in making as many duplicates as may be desired. The engineer who wishes to make such copies should proceed as follows: Purchase sensitized blue-print paper, which comes in 10-yard and 50-yard rolls. Procure a print frame of convenient size from the dealer or have one made. It is a strong frame made to hold a glass like a picture frame. The back is in one or more pieces, and movable, and is clamped against the glass by means of cross-bars and buttons on the back of the frame. To make the print, place the face of the tracing against the glass and upon the tracing lay the face of the blue-print paper, place a mat of thick papers or other cushion upon this and clamp the back upon it so that every part of the drawing will be pressed tightly against the glass. Expose the glass to the direct rays of the sun for four or five minutes, then take out the print and wash it in a bath of clean water until the paper turns to a clear blue, and the lines show a clear white, when hang up to dry. If the blue is pale, the exposure was too short; if very dark, it was too long. Other processes will give blue lines on a white ground and black lines on a white ground. These require that a paper negative be made from the tracing and special and more expensive print paper be used. Blue-printing establishments in the cities make copies of these kinds at a reasonable price so that the engineer will usually find it to his interest to send his tracings to them when he desires such prints. One advantage which they possess over blue-prints is that they can be worked upon with ink and color in the same manner as hand-drawn maps on white paper.

Reports and Estimates. Every drainage project that is worked out by the engineer requires a report which should be complete but not necessarily elaborate. In some instances maps and estimate-sheets need but little

more than an accompanying statement of the project which has been worked out, the problem which received particular attention, and the plan which is recommended.

In other cases the subject should be discussed thoroughly in an unbiased manner, for it should be remembered that assertions and opinions are out of place in an engineer's report unless he can support them by facts and sound reasoning. The facts should be presented in a logical order, and expressed in terse and clear language, and should, as far as possible, be free from technicalities. In reports upon public drainage districts, the economic features of the undertaking should be covered comprehensively and the entire situation discussed in a spirit of fairness and in accordance with the facts which have been developed by the survey. This is particularly important because the entire proceeding becomes a matter of record and will be open to the public for reference and criticism. The importance of this matter of reports cannot be too strongly urged upon the engineer, and he will do well to rearrange and rewrite his reports until they assume the best form possible. The following suggested outline covers the main points that should be included in **a drainage report.**

- **a.** Location and area of the tract surveyed; distance from supply of construction material; facilities for transportation; location of market for produce.
- **b.** Natural drainage channels, number and size; area of watershed; proportion susceptible of improvement; fertility of the soil.
- **c.** Natural surface conditions; character of land and soil; areas of cultivated land, timber and wet portions; general need for drainage; rainfall and climate; estimated run-off.

d. Method used in making the survey; length of lines run; marks left on the ground; results of the work.

e. Plan of improvement proposed and recommended (the maps, profiles and other drawings should be referred to and explained if necessary); methods of construction.

f. Estimates of cost in classified form; time required to construct the work; difficulties liable to be encountered, with proposed method of overcoming them.

g. Benefits that will follow. These should be particularized, as for example: benefits from increased production of the land, benefit to health, to public roads, to adjoining towns by reason of increased purchasing power of the surrounding country, increased revenues for public improvements and education.

h. List of bench-marks, with bearings and lengths of located lines may be added when desirable.

CHAPTER IV

DRAINAGE AND HOW ACCOMPLISHED

THE principles upon which the practice of drainage rests are very simple, and a perfect understanding of them will enable the engineer to adjust a drainage scheme to each varying situation, even though he may encounter new problems, in the solution of which there are no established rules of practice to guide him.

Drainage is the removal of surplus water from the soil, whether accomplished by nature or by channels artificially constructed. Surplus water is the excess above that needed from day to day for the use of plants and that stored in the lower strata of the earth as a reservoir supply during times of drouth.

Soil-Water. All water in the soil has come primarily from some form of precipitation upon the surface. Where adequate drainage is provided there remains in the upper soil twenty-four hours after a rainfall, more or less, only the film-water, or moisture, needed by plant life. This clings to the soil particles by surface-tension and not being affected by gravity is never removed by drainage. The rest of the rainfall which entered the ground has either passed out of the soil through underground channels into neighboring surface streams or percolated into the lower strata of the soil, there to become a stationary supply.

This free water in its passage through the soil occupies the air spaces, the air being temporarily crowded out during the time. When we appreciate the fact that the presence of air within a soil is as essential to its

healthy condition and the growth of plant life which it supports as is moisture, it becomes plainly apparent that too-long occupation of the air-cells by water will do harm. This occurs when there is no ready way for the escape of the water. In a soil completely saturated with stagnant water every space is filled with it to the entire exclusion of air, and a soil whose drainage is imperfect in any degree is deprived of some of the needed air supply, the injurious effects being proportional to the amount of occupation of the air-cells by water. These effects are, in part, a sour, wet, uncultivable soil, on which grasses and grains are either entirely drowned out or are stunted and sickly in growth, having little vitality. The object of artificial drainage is to aid nature where necessary by supplementing such natural channels as exist by others so constructed and placed as to provide for the egress of the water not needed in the soil. Being an aid to nature, it is evident that it should imitate nature's methods as far as practicable.

Open Channels as Drains. Surface watercourses of all kinds are among the natural means afforded for drainage, and the artificial open channel constructed where these do not exist is one of the ways by which natural drainage may be supplemented.

Open channels, whether natural streams or artificial ditches, receive water which flows over the surface of the ground and that which passes through the soil. In ground composed largely of sand with a gravel subsoil, open channels are an effective and sometimes a sufficient method of drainage, as the open nature of the soil permits free percolation of water, first from the surface through the upper stratum into the gravel and thence laterally into the channels.

But in a heavy clay or loam soil, open channels afford only imperfect drainage, owing to the slow percolation

of the water through the soil and to the fact that the sides of a clay ditch are more or less puddled by the flow of the water, thus impeding the passage of the water into it.

Where the soil is absorptive and the land moderately level, or even on considerable slopes when the rainfall is slow, water does not pass to the ditches until the soil is completely saturated, after which the entire volume falling flows over the surface, while the water in the soil begins also to find its way through underground channels to the ditch.

On land with dense soil, smooth surface and considerable slope, or even on more level land of this nature in times of heavy and precipitous rainfall, or on any soil while frozen, a large part of the falling water flows over the surface directly into the ditches, sometimes before the soil has time to absorb it. This is not a desirable condition, because the water is given no opportunity to replenish the supply of moisture or of bottom water for use when rainfall is deficient. For this reason, where artificial open ditches are the only ones provided in such places, care should be taken to so locate them that the drainage water will not be too rapidly removed, but will pass into the soil and remain there for a sufficient length of time to supply it with all the moisture it needs. This result is not easy to obtain, but the skilful engineer may approximate it.

Underdrainage. Underground drainage channels which permit the absorption of the needed moisture by the soil, as the water slowly percolates through it, provide the most satisfactory drainage. A stratum of gravel or sand below the upper soil is Nature's method of perfect underdrainage, the water passing readily through it to some point of discharge. But frequently the nature and slope of the subsoil are such that the water is

held in the upper soil. To relieve this condition, artificial underdrains of clay or concrete are laid at a depth and in a direction to aid nature by the removal of the surplus water. These do not interfere with any existing natural channels, or pores, in the soil, but on the contrary tend to increase their size, by the added flow through the soil induced by the presence of artificial drains. No drainage would be necessary, since gravity would draw the water directly down through the ground, were it not for the resistance of the particles of soil. These prevent the water from obeying the law of gravity, and the underground drain is constructed to form a passage through the soil where the water may be free to respond to the law. The water in the soil nearest the drain passes into it, thus starting a flow which is constantly augmented by water from more distant points flowing to fill the space vacated. Thus a steady movement of water through the soil toward the joints of the tile is created, the water entering the tile at those points. The effect of this is to reduce the height of the water-table, or plane of saturation, in a curved line, the highest point of convexity being midway between the drains, and the lowest point immediately above them. This curve gradually flattens as more and more water passes into the drains. The weight of water in the soil above the line of tile increases the pressure and causes a more free and continuous flow than in an open ditch.

It would seem at first thought that underdrains would be inoperative when the ground is frozen, but this is not always the case. The least softening of the surface makes at once available the shrinkage-cracks, worm perforations and decayed root cavities always present in the soil, which become drainage pores and bear surplus water to the drains, that are thus found discharging in midwinter.

Sources of Water in the Soil. As in the case of a physician whose skill is tested not so much by his ability to administer the proper remedies, once the disease is known, as to locate the trouble and give a correct diagnosis, so the skill of the engineer may be tried most severely to discover the source of the water which is doing the injury. While all water in the soil, as before said, comes primarily from precipitation, that which demands removal may have come immediately from various sources, requiring different treatment to effect thorough drainage. Wet land may be the result of the rainfall upon it held in the soil by the impenetrability of the subsoil immediately below it, in which case an arrangement of underdrains so as to open channels in the soil and subsoil and carry the water to a proper outlet will remove the trouble.

Or the wetness may be produced by water from a spring which has flowed on top of an impervious stratum in the subsoil for a distance, finally issuing on some side slope, perhaps. When the water is from this source a plan of drainage which shall tap the underground stream and lead the water off safely before its discharge upon the injured land will solve the difficulty.

Or it may be, as in the irrigated regions, that water has seeped or percolated through the soil from some stream or body of water on a higher level. This percolation may take place many feet below the surface of the ground, the water gradually rising in the soil until it reaches the roots of plants. What is needed in such situations are intercepting drains placed at a sufficient depth to cut off the percolation and carry the water away.

Thus it is evident that the source of the water giving trouble must never be taken for granted by the engineer without proper investigation, as the method of drainage which he should recommend depends upon it.

Relation of Soils to Drainage. A drainage engineer should, as part of his preparation for his profession, make a thorough study of soils, as their various structures have much to do with their drainage properties, their need of drainage, and the ease or difficulty with which it is accomplished. He should be familiar with the kinds of vegetation which different soils produce, so that by noting the nature of the vegetable growth upon any tract he is considering, he can judge the characteristics of the soil supporting it. As will be found in the succeeding chapters, the nature of the soil, whether open and porous, or dense and close, whether sand or clay predominates in its structure, is an important factor in determining size, depth and frequency of drains. Because the thorough discussion of soils cannot be given place in this book, it has been thought best to make no attempt in that direction, but to advise the engineer to study a good treatise on soils as an essential part of his training.

Conservation of Moisture. An important office of drainage is to place the soil in a condition to receive and retain the largest possible amount of capillary moisture, and plans should be so devised that this object may be secured, as well as the removal of the water which, if retained, would prove injurious. One fact deserving particular notice is that the excess of water while moving through the soil works no injury, but the effect of stagnant water upon the condition of the soil and upon plants is immediate and pronounced. That is, a slow but continuous movement of the water downward from the surface toward a drain of any kind serves to admit air and heat, while at the same time the full amount of capillary water is stored as the process of removing the surplus goes on. Let this movement be stopped but a day and the effect upon vegetation is soon manifest.

While it may hardly be possible to drain clay soils too completely, there can be no doubt that for many other soils the depth, distance apart, size, etc., of drains should be adjusted not only with reference to the removal of surplus water, but also to the storage of moisture as a reserve, by means of which the effects of drouth may be largely ameliorated.

Beneficial Effects upon the Soil. The effect produced upon the soil by underdrainage is usually marked. The removal of the water downward through the soil permits the entrance of warm air. This aeration of the soil soon modifies its texture, or structure, causing it to become friable and easy of culture.

It also increases the depth of soil available to plant life, and makes possible an extended range of roots, with consequent increase in vigor of growth of plants.

A soil properly drained will endure alternate freezing and thawing without "heaving" the growth upon it so as to expose the roots, as frequently happens on undrained land.

The conditions most congenial to nitro-bacteria, are air, moisture, and warmth, and these exist more perfectly in a drained soil than in any other.

Drainage causes a slight loss of nitrogen, but not a sufficient amount to seriously deplete the supply or produce any marked effects.

Visible Results of Drainage. As the engineer is often called upon in large district work to convert some skeptic whose cooperation is desired, convincing him of the importance and necessity of the work, he should be familiar with the visible improvements resulting from drainage, and be able to enumerate the benefits attending it in a convincing manner. The readiness of the land for seeding earlier than neighboring undrained land; the quicker start in growth of the crop; its greater

ability to withstand drouth; its escape from injury by heavy rains; its partial or entire immunity from bad effects of frost; its increase in quantity and consequent increase in profits; the improvement of sanitary conditions; all of these the engineer should be able to elucidate in such a way as to carry conviction.

CHAPTER V

THE PRELIMINARY SURVEY

When the drainage of any tract of land is contemplated, whether by open ditches or underdrains, a certain amount of preliminary investigation is necessary in order to get a clear idea of the situation, and a general knowledge of the nature and amount of work that will be required to accomplish the purpose. This is true whatever may be the size of the territory in question, though naturally the larger the area the more time must be given to preliminary work.

The first thing which should engage the engineer's and owner's attention is the critical consideration of the natural or inherent fertility of the land. Not all land that can be drained is worth the cost. Nor will it all be equally valuable after reclamation, for various obvious reasons which the engineer should not fail to perceive. The financial attractiveness of the proposition will largely depend upon the prospective value of the crops that can be grown. Some wet lands have a thin soil, that is a few inches of loam, clay, peat or muck resting on sand. Some are hard clays, difficult and expensive to drain and deficient in fertility, and others will be limited in their production to one or two kinds of crops. Still others will produce profitable crops only by the liberal and continued use of fertilizers. Equally fertile land may differ greatly in the expense and length of time required to subdue, clear and place it in shape to yield returns. This phase of the proposition should be canvassed by the engineer in consultation with the property owners,

and the land fertility questions decided if possible before proceeding farther with the examination.

In all drainage projects which come under State drainage laws, the engineer must not fail from the outset to see that all surveys comply with the requirements of the law of the State in which he is working. He should always bear in mind, also, that while drainage must be developed along natural lines, its reference to that artificial network known as property lines must never be overlooked, since in the final adjustment and record of the work they play an important part.

Preparatory Inspection. The first step in the preliminary survey of any project, be it large or small, is a preparatory inspection or reconnoissance by the engineer, before any instrument-work is undertaken. This is of very great importance and should never be omitted, as it enables him to determine what kind of a survey should be made, where it should begin, and how it can most advantageously be conducted, thus preventing waste of time and needless labor later on. Such a preparatory inspection should be sufficiently thorough to acquaint him with the main features of the tract under surveillance. He should note the number and general location of waterways or swamps; the proportion of cultivated land, with the nature of its products; the kind of soil, both with reference to the ease with which it may be drained, as an important factor in determining the method to be employed, and with regard to its probable value for agricultural purposes when drained, that he may form an opinion as to whether the after returns will justify the cost of drainage; the approximate area of the watershed; the probable location of the outlet; the situation of any farm-houses or settlements within the territory. In short, he should acquire a mental picture of the salient features of the landscape

supplemented by memoranda and pencil sketches to refresh his memory. In the case of swamps or other extensive drainage undertakings, the engineer, in addition to the most thorough personal inspection it is practicable to make, should collect all available data previously secured by others bearing upon the area under consideration. These should include copies of the U. S. Land-Office maps of the district, if such exist, or any other procurable maps, such as topographic sheets for determining the extent of the watershed; a record of government or other bench-marks that may be useful for reference; the records of flood-planes and high-water marks of streams which may be utilized as outlets, and of rainfall for the section during a period of years. So many considerations must enter into the evolution of a successful plan of drainage for large areas that the engineer can hardly have too complete an array of pertinent facts.

Preliminary Instrument-Work. The nature of the problem is sometimes such that a thorough preparatory inspection by the engineer may be all that is needed before the actual location survey is made. This is quite likely to be the case in small projects, or where the slopes are so pronounced as to indicate at a glance the main lines of the system. But more often preliminary instrument-work is also needed before the engineer has in his possession sufficient data to map out a system of drains.

Whatever the size of the project, or the nature of the land whose drainage it is desired to effect, the first thing to be established is **the location of the final outlet** for the entire system, with a careful investigation as to its sufficiency for the purpose. This may have been determined in the preparatory inspection, but if not, such levels must be taken or measurements and estimates

made as will enable the engineer to reach a decision, for upon this point he must base all his plans.

Lands subject to investigation vary so greatly in character as to require different treatment, and various methods of preliminary surveys are employed to meet the conditions. Thus farms or plantations, overflowed valleys with their streams and bottom lands, level table-lands, uncultivated or partially improved, swamps wholly unreclaimed, all present different problems.

For Farm Lands. In the preliminary survey of farms or plantations it is convenient to use the boundary-line as a base. Assuming that the work to be done is the drainage of an 80, 200 or 600 acre farm, begin the survey by establishing a bench-mark at a convenient point in the boundary-line. From this starting-point run a line of levels entirely around the tract, closing on the point where it began. Set reference stakes every 600 or 800 feet, numbered with the distance as determined by the stadia, and take levels at all high and low points, so that when the circuit is completed the field-book will show where surface-water enters and leaves the tract, and where an outlet can be secured. The line also serves as a base to which interior surveys can be referred and checked. Level-lines may then be run across the tract at such places as may be selected, and with the aid of the compass and stadia the low and high places in the interior can be located and their elevations recorded.

Another method, which is better adapted to some tracts, is to run a base-line through the interior, setting permanent hubs in the same manner as in the method where the boundary is used for a base. From these stations run lines to such points in the field as may be selected, locate them by compass and stadia, and take

their levels, using the stations as bench-marks so that all will be referred to the same datum. A sketch should be made in the book to show approximately the location of the points and the correct elevations as determined by the level.

For Valleys. A valley usually has a well-defined watercourse, a swale or a depression which may when improved be utilized as the main drainage channel. Upon inspection it will be seen that such a line should be the location of the arterial channel which is constructed to carry the drainage from a certain watershed which must be determined. The most natural method of getting such a project into shape is to use the watercourse as a base and run lines laterally from it wherever it may be desired, or, if the area is quite level, at regular intervals of 1,000 or 2,000 feet. If the watercourse is small, a corrected line may be established by inspection and the center line for the improved ditch may be staked permanently. If the work is for preliminary estimate, the line may be run by compass and stadia, reference hubs and bench-marks being set at convenient points. Side lines can be run from these to other parts of the tract for the purpose of securing the topography that may be needed. A part of such work should be to ascertain the watershed or approximate boundary-line of the drainage-unit, or basin which will deliver its water to the outlet that it is proposed to improve. The tract which is to be drained may not include the entire area, but when plans are made for the outlet this should be taken into account and provided for. Two important points in the location of mains and outlets should always be kept in view by the engineer. The outlet to the entire system must be fully investigated and the measure of its efficiency determined as before pointed out, and the main drains must be so located and have such depth

that remote parts of the tract can be drained into them, whether constructed with the rest, or years later.

For Swamps. Surveying swamps for drainage is often unpleasant and more or less difficult, for obvious reasons, yet upon no class of land is the value of a good preliminary survey more manifest. The development of a proper method of draining them is dependent upon accurate information which is revealed only by the survey. The engineer must have data regarding the surface-slope of the several parts of the tract; the location, depth and size of all watercourses that may exist; the size and depth of ponds and lakes, and the area of the watershed. Owing to the magnitude and level character of swamp districts, such data must be obtained by instrument-work before a drainage system can be intelligently designed, and the preliminary survey should be sufficiently complete for that purpose. The exercise of no little judgment is required on the part of the engineer to decide what the preliminary character of the work should be.

It is probable that no single level-line reveals as many of the topographical features of a swamp or valley with respect to its drainage, as one extending directly across the slope. It shows the position, size and depth of watercourses that exist, and the relation of the land on either side to them. Appreciating the value of such lines we may outline the following method of making a preliminary swamp survey. Run a series of level-lines across the slope and general course of drainage, at intervals of one mile, following U. S. Survey lines, if any exist, and establishing new lines in territories where such surveys have not been made. Take distances by stadia and establish bench-marks at selected and convenient points for future reference. Locate all water-courses, drainage-channels and ditches

which the line traverses, and ascertain the width and elevation of the bottom of each. In addition the watercourses and other channels which may be of possible use for drainage, should be meandered between the points where they intersect the several lines of cross-levels.

Records of Survey. The results of all preliminary surveys should eventually be transferred to paper and made a matter of record. To this end field-notes should be clear and sufficiently explicit. An engineer's field-book, as has been said before, should always be complete enough to be self-explanatory, if by chance it becomes necessary for another engineer to take up the work at any point. The columns on every page of the level-book should be properly headed, while the method used in recording the azimuth of a line or stadia notes should be described on the first page. The entry at the beginning of each new survey should state its purpose, and be accompanied by a sketch-map of the land to be covered by it. Sketches of details of parts of the work presenting special or important problems should be fully made. Elevations obtained by the instrument-work should be put on the sketch map, since it is often the case that comparatively few levels are sufficient for determining a plan of main drainage. It may be desirable to plot the survey to a scale for the purpose of more minute and leisurely study of the problem, or for estimating the cost prior to making a location survey. The entire tract will fall into drainage subdivisions of greater or less area which should be shown upon the field-book, or upon the more accurate scaled map. Field data should be plotted, as far as practicable as the work proceeds, upon a scale suited to the magnitude and purpose of the work. The principal elevations should be recorded on this map; streams, sloughs and ponds

should be sketched in and bottom elevations shown; public roads, if any exist, or railroads and other public improvements should be represented.

With this done, the engineer has before him in concise form the information required to enable him to plan the main drainage system for the entire area in a comprehensive manner. He can make an intelligent estimate of the number and size of the drainage channels required, and represent them with close approximation on the map. He is also prepared to estimate the cost of the main system and work out the method that should be employed in developing the possibilities of the entire project.

CHAPTER VI

UNDERDRAINS AND THEIR LOCATION

For over half a century in this country, farm and field drainage under ordinary conditions has been accomplished in the main by tile of various sizes up to 12 inches in diameter. Some of the advantages of underdrains over open ditches are so obvious that they appeal to the farmer whether he knows anything of the science of draining or not. The doing away of the unsightly open ditches which cut across his farm, occupying many acres of valuable land, causing serious inconvenience to avoid them in field operations, costing no little labor and expense to maintain them in good working order, is such a tangible and self-evident advantage that the average farmer is very ready to substitute underdrains for open ditches even before he has learned that the condition of his soil is better when underdrained than when open ditches are used.

The value of conducting water in underground pipes has become so highly appreciated that large public or district systems of drainage are now constructed of tile where open channels were formerly used, pipes as large as 36 inches in diameter being frequently employed for this purpose.

The Outlet. Outlets for tile systems in level areas usually discharge into streams or ditches which run full at periods and for a time submerge the outlet of the tile. This is often unavoidable, yet the condition is frequently responsible for the unsatisfactory operation of tile systems at a time when their service is most needed. The

submergence of the outlet is sometimes only temporary, as the flood-stage of the stream soon subsides, giving a comparatively free discharge to the drain. When possible the outlet should be located where it will not be submerged. If the main line follows an open channel it should be deflected near the outlet so that the open channel and the tile-drains will not discharge together. The system should be planned with as few outlets as practicable, and these should be protected in a substantial manner (See Figs. 28 and 29, Chap. XI). In representing the system on maps, they are the points to which the whole is referred.

Principles Governing Location. The engineer will do well to keep in mind certain cardinal principles which though simple are important in locating drains. In general, the main should be located in the line of natural drainage, for the obvious reason that the surface slope of the land leads the water in this direction, and also because the stratification, particularly of alluvial and glaciated soils, permits water to percolate more readily toward low ground. There are exceptions to this, which will be mentioned later.

Drains should be in straight lines as far as possible, and changes in direction should be made by long curves. This principle should not be carried out to the extent of cutting through ridges which require no drainage, when the drain may be laid through low land around the ridge and yet accomplish the desired purpose at its objective point. It is usually the case that the line of natural drainage may be straightened by short cuts here and there in such a way as to make the drain less expensive and more efficient without impairing its value as a drain for the natural course. These factors in location must be determined on the ground.

Submains should also follow the line of natural drain-

age as far as possible, and laterals should be laid in the line of greatest slope. There are exceptions to this principle, but they apply to particular cases where it is necessary to intercept soil-water which percolates through the soil from a higher level, being aided or modified in its flow by hard-pan, gravel or sand strata until its course is checked by some less pervious formation. In such cases intercepting drains laid across the slope at the proper depth are necessary to drain the bog which receives such water.

When drains thus laid fail to accomplish the purpose, it is because they have been placed above the level of the seepage water, thus permitting it to pass under them unchecked. The experimenter is apt to think it has entered the tile at one side and passed out of the other and down the slope, and to conclude that drains across the slope are ineffective.

Avoid short laterals where a system can be adopted in which long parallel laterals can be used. This is a matter that relates to the economy of the work rather than to its efficiency. Every main or submain will of itself drain the land for a certain distance on either side of it. In order to reach the mains, the short laterals must extend through the belt of land thus drained, and hence a part of each lateral will be useless except to conduct the water to its receiving drain. The fewer junctions there are in a given tract, the less waste of length of laterals will there be. There are localities, however, where, on account of the contour of the land, short laterals are necessary.

Locate the lines so that all the land can be thoroughly drained when the system is fully carried out. The preliminary examination will furnish the information needed regarding the character and elevation of the land, so that this can be done in a comprehensive way.

Systems of Drains. The various methods of arranging drains for accomplishing the work required in accordance with the foregoing principles are called systems.

The natural system consists of lines of tile laid in natural depressions that are wet and require draining more than the adjoining land (**Fig. 14**). They are aids to natural drainage, and complete it in localities where the adjoining higher land is naturally drained by the

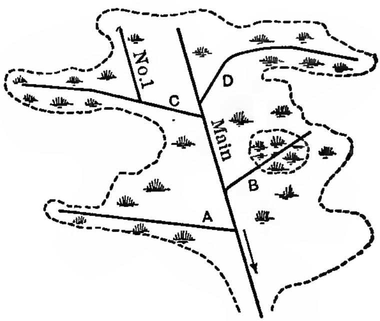


FIG. 14.—NATURAL SYSTEM.

low depressions. Such random or occasional lines are called upon to carry the drainage of both dry and wet land, which fact is often overlooked in apportioning the sizes of tile that should be used. The natural system is the skeleton which may be developed into a more elaborate one if later found necessary.

The herring-bone system consists of a main with parallel laterals joining it on each side in the manner indicated by the name (**Fig. 15**).

The gridiron system consists of a series of long parallel laterals which discharge into a receiving drain from one side only (**Fig. 16**). It is one of the most economical and efficient systems used in treating level lands.

The grouping system (**Fig. 17**) takes its name from the method of collecting a number of laterals into a short main which would otherwise discharge into a ditch direct, thus making one outlet serve several drains.

The double-main system is applicable to broad, flat sloughs, where it is desirable to use two lines of smaller tile instead of one large main through the center. If the land on either side has a good slope toward the slough

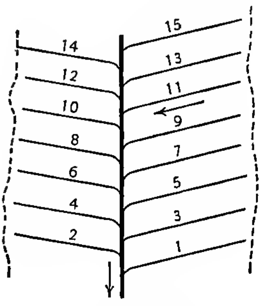


FIG. 15.—HERRING-BONE SYSTEM.

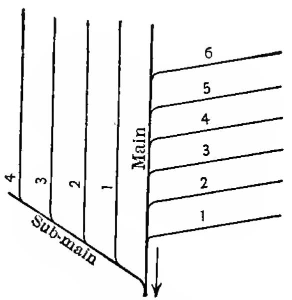


FIG. 16.—GRIDIRON SYSTEM.

a line of seeped or boggy land may have developed at the base. A main laid on each side as an intercepting line with laterals on the slope, as shown in **Fig. 18**, will be effective, if the drain is placed as deep as the stratum through which the water percolates.

The Elkington system was originated by Joseph Elkington of Warwickshire, England, in 1764. As now used, it consists of a few single lines of tile so located as to intercept seepage-water which percolates down a slope. In case the drain is not deep enough to fully intercept the water it is supplemented by wells which are made directly beneath the drain. These wells penetrate the strata from which the water proceeds, and are made with an auger if the earth is firm clay, or are

excavated and curbed with lumber or brick if the soil is loose and unstable. In some instances the wells are filled with loose gravel. The office of such wells is to intercept the deeper currents of water. The pressure which forced the water through the soil causes it to rise in the wells and flow off through the drain which

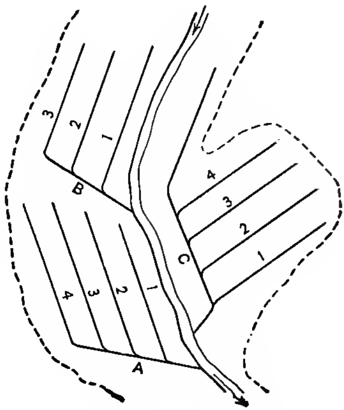


FIG. 17—GROUPING SYSTEM.

serves as an outlet to them (Fig. 19). This system is applicable to the drainage of bogs and springs, and is successfully used in draining irrigated land.

Depth of Drains. No question relating to underdrainage is susceptible of a greater variety of answers than that of the proper depth of drains. With regard to depth of drainage, 4 to 4½ feet is called deep, 3 feet medium, and 2 to 2½ feet shallow. Advocates of deep and shallow drainage have argued their favorite theories since the time tile were first introduced. It is one of those cases in which theories are not always verified by practice, the factor which prevents this being the variations in the characteristics of the soil which is to be

drained. In order that any one theory may prove correct it must apply to a soil of given characteristics. When it is said that no universal rule for depth can be safely announced, it does not follow that a safe rule

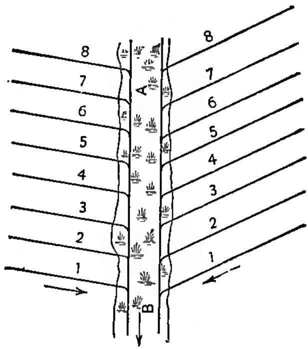


FIG. 18.—DOUBLE-MAIN SYSTEM.

can not be given for a locality whose soil-structure and climate are known. If an engineer's practice is confined to a region having the same kind of soil in all parts, he can adopt a rule of depth and safely adhere to it in

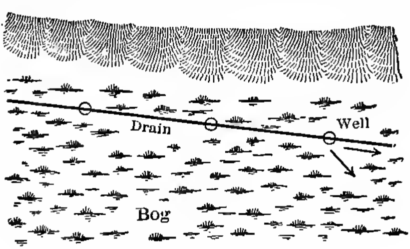


FIG. 19.—ELKINGTON SYSTEM.

every case perhaps, but if this region is one where the soil is open and responds readily to deep drains, he will fail if he applies the same rule to the dense clay soils which he may encounter in other localities. It is de-

sirable that clay and loam soils be drained and aerated as deeply as practicable, but this operation requires that the water be removed from the surface within a reasonable time so that the sun and air can act upon the particles of soil as the water recedes. The resistance of close soils prevents this if the drains are too far distant from the surface. Hence it is found that in some close, heavy soils drains at 2 to 2½ feet give good results where those at 4 feet fail. Many of the rich farming lands in the Middle West, with permeable soil, should be underdrained 4 feet deep, as the successful operation of many miles of drains at that depth attest. A general rule of depth then, for humid regions, is from 2½ to 4 feet, depending mainly upon the nature of the soil. In irrigated land, however, it is found that drains placed 6 or 7 feet deep accomplish the desired result, while those 4 feet deep may fail to do so.

Before deciding this matter for lands with which he is not familiar, the engineer should test the soil with reference to its permeability to water. This can best be done by digging small pits where the land is wet, by means of which its physical structure and the freeness with which water seeps or percolates through it can be examined and conclusions deduced regarding the depth it will be best to place drains. In this connection it may be suggested that the drainage of dense clay soils can be materially facilitated by stirring the soil deeply, or subsoiling, thus breaking up the compact strata which are frequently found 6 to 12 inches beneath the surface.

Frequency of Drains. The proper distance apart of drains is a subject that is closely related to their depth, since soils which respond best to shallow drains require them placed closer together. Efficiency and economy are factors in this part of the problem. If drains placed 100 feet apart give satisfactory results, nothing

is gained by placing them 30 feet apart, while the cost is greatly increased. On the other hand, the former distance in some cases will be so ineffective as to hardly warrant the work. Depth does not compensate for greater distance except in a limited way. As a guide to the judgment, the following distances for the kinds of land described are suggested. They are the result of observations and experience in a wide range of conditions. In close, dense soils, largely clay, 30 to 40 feet; coastal plain lands composed of mixed clays with fine sand and uniform structure, 60 feet; alluvial gumbo or heavy soils, but with granular structure, 70 to 80 feet; alluvial, glacial drift and sandy loam soils, with joint clay subsoils, 100 feet; sandy lands and soils containing considerable quantities of vegetable matter and those with subsoils having a liberal supply of sandy or gravelly material, 150 to 200 feet. These suggestions apply to drains on level lands and should be considered in connection with depth and needed accessories referred to elsewhere.

Staking out Lines. The general system having been decided upon, begin at the outlet of one of the mains to stake out the lines preparatory to construction. Suitable stakes should be prepared beforehand. These may be made of fence lath 4 feet long, 1½ inches wide and ⅝ inch thick, cut in pieces 16 inches long when intended for use on land which is free from grass and heavy weeds, but otherwise 2 feet long. These are called guides, and serve to carry the station-numbers and show the location of the grade-stakes. An equal number of grade-stakes made of the same material and one foot long should be made to accompany them. Where the ditches are to be dug without much delay, stakes made of plastering lath, which are more easily carried, may be used for guides.

First set flags at points along the course of the proposed drain by which to line in the stakes. Set the first, or 0 stake, at a selected distance on the right of the outlet, such distance depending on the size of the ditch that is to be excavated; drive it flush to the surface and set the guide-stake on the line and about 4 inches beyond it, as shown in Fig. 20. The link chain is convenient for measuring distances. Let the fore-chainman hold the forward handle of the chain and with it a guide-

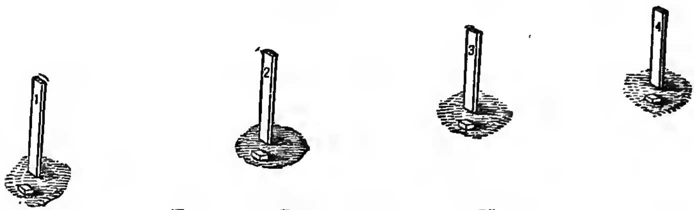


Fig. 20.—Guide-stakes and Hubs.

stake in a vertical position, and let the rear-chainman with the handle of the chain over the grade-stake, and his eye directly over it, line the fore-chainman's stake in by the flag-pole which marks a point on the line. The fore-chainman sticks the stake where directed and drops a grade-stake by it. He then pulls ahead another length and is again put into line. The rear-chainman drives the stakes and marks the guides with a heavy lead-pencil or marking-crayon, or has an assistant do so. The stakes are marked consecutively, giving fractional distances, as 3 + 20, etc. Grade-stakes placed regularly 100 feet apart, with fractional stakes where necessary, are ordinarily close enough together for use in constructing the drain. If the stakes are well lined "by the eye," as described, the more tedious method of lining in with an instrument is avoided and the work, for practical purposes, is just as accurate. The bear-

ings of the tangents, however, should be taken with the instrument.

Where curves are made, intermediate stakes should be set in such a way that they can be followed and used in digging the ditch, and should be marked so as to indicate the number of feet from the outlet up to each stake. As for example, between **Stations 5 and 6** the intermediates are set 20 feet apart and should be marked **5 + 20, 6 + 40**, etc. Another point to be noted is the place where submains or branches are to join the line. The number of each branch should be marked upon its proper junction-stake.

The same plan should be followed in staking drains throughout the entire system. Begin at junction-stakes and stake each line as a unit, numbering the stakes consecutively up grade, placing upon the upper-end stake its full number and the name which is given to the line, so that a workman in looking over the system can follow the lines from either end, by schedule or map.

Designation of Drains. Some orderly method of designating drains is necessary where there are many of them in a system so that notes can be kept without confusion and also correspond with the schedule and plat which should be made after the work is staked out. Mains may be designated as **Main A, Main B,** etc.; submains as **Submain No. 1 of Main A**; branches of a main or submain should be numbered **1, 2, 3,** etc., up from the 0 point of the main or submain. All numbering and lettering of the drains is done consecutively from the outlet toward the upper ends. Where there are two or more unit-sections with separate outlets in the same farm or plantation, they may be distinguished as **Drainage Section No. 1, No. 2,** etc., or by some local name, as **Crooked Creek Section, Flat Woods Section,** etc.

Taking Levels. Levels should be taken upon each

LEVELING FOR DRAINS—FORM FOR FIELD-BOOK

Main A

(Left-hand Page) (Right-hand Page)

Sta	B S	H I	F S	Elev	G L	Cut	Remarks
0	6.45	106.45		100.00	97.25	2.75	Grade .25 to 100 ft.
Outlet			9.20	97.25			Bottom outlet ditch
1			6.32	100.13	97.50	2.63	
2			5.92	100.53	97.75	2.78	
3			5.61	100.84	98.00	2.84	
4			5.12	101.33	98.25*	3.08	* Change grade .20 to 100 ft.
4+50	7.10	108.94	4.61	101.84	98.35	3.49	Branch No. 1 enters —.2 in.
5			6.72	102.22	98.45	3.77	drop
6			6.11	102.83	98.65	4.18	
7			6.72	102.22	98.85	3.37	
8			7.21	101.73	99.05	2.68	
9			7.11	101.83	99.25	2.58	
10			7.40	101.54	99.45	2.09	Pond
11			7.10	101.84	99.65	2.19	Ends 25 ft. from S. line of field

Bearings

0– 3 S., 3° W.
3– 7 S., 25° W.
7–11 S., 5° E.

Note

Outlet of drain on line of farm is 350 ft. W. of N. E. Cor.

The profile of the above notes shown in Fig. 21.

grade-stake and recorded in the note-book in the manner shown in the accompanying specimen page of a field-book. The notes for each line should be kept under its appropriate head or name, and all levels should be referred to a common datum. The bearings of the lines should be recorded on the right-hand page of the book opposite the level-notes so that all of the data concerning each line will be recorded on the two pages which open opposite each other.

Establishing Grade Lines. The grade upon which the tile is to be laid must be determined by measurements downward from the grade-stakes. The grade

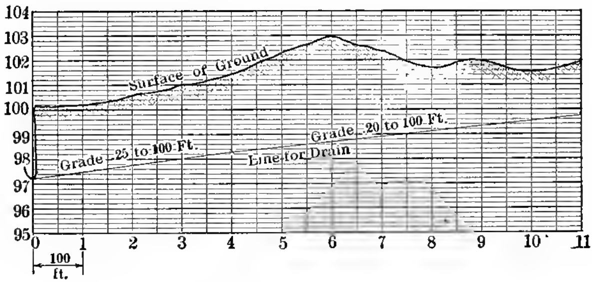


FIG. 21.—PROFILE OF MAIN A.

may be laid out by either one of two methods. The levels may be reduced to a profile which represents the surface-line upon such a scale that differences of $\frac{1}{10}$ ft. in elevation can be shown (**Fig. 21 and notes**). The grade may be located upon this by drawing trial lines in pencil or by using a black thread which can be shifted about until a satisfactory grade is found, and the rate from point to point determined. Another method is to select trial grade-line elevations along the line until the grade and depth at various controlling points are satisfactory. These points may then be entered and depths computed throughout the entire system without the aid

of profiles. This is the most expeditious method and can be used in all ordinary underdrainage work.

Grade is expressed in feet per 100 ft., or in feet per mile. It is convenient to adjust the grade to an even .01 foot, as for example, .02 ft. per 100 ft. = 1.05 ft. per mile; .05 ft. per 100 ft. = 2.9 ft. per mile; 10 ft. per 100 ft. = 5.28 ft. per mile. It is also expressed as a percent, as .02% = 1 ft. in 5000 ft.

Two columns should be added to the note-book, one for recording the elevation of the grade line at each station, and headed G L, and the other for recording the depth at each station and headed Cut. After the rate of grade has been decided upon, the amount of rise for each station must be added to the grade-elevation of the preceding one and subtracted from the surface elevation to obtain the depth of bottom from the top of the grade-stake.

Examining the notes (page 84) from which the profile illustrated has been plotted, we find that a grade of .25 feet per 100 feet has been decided upon and that the outlet of the tile can begin at the bottom of a ditch whose elevation is 97.25. This subtracted from the surface-elevation at 0 station shows that the drain will start 2.75 feet below the surface. Add .25 to this grade-elevation and to each succeeding one, and subtract each from the corresponding surface-elevation. The result in each case will be the depth. These points when connected will make a straight line. When a change of grade is to be made, note the station at which it begins, and also the amount of grade, and proceed as before. The depth at which it will be desirable to make the drain will be a factor, and also the minimum grade which may be used. Drains laid on as low a grade as ½ inch to 100 feet are in successful operation, and frequently no greater one can be obtained. If possible,

however, a grade of .10 foot per 100 feet should be secured, though a failure to get as much should not prevent the use of tile.

A uniform grade should be used from point to point and computed by taking the difference between the elevation of two grade-line points and dividing by the length of line between the two. Where a cut is to be made through a ridge to a flat which it is desired to drain, determine the least depth of drain that should be used at the upper end, adopt a safe minimum grade, say .10 or .20 foot per 100 feet, and run down the line, subtracting the amount of grade from the grade-elevation of each station in order until the ridge is passed and the desired depth is reached, then change to a heavier grade. This is the ordinary method of grading a drain, reversed.

When a submain or a lateral enters another drain it is best to have an outfall from the branch line into its main. This is commonly called a "drop," and the amount should be proportionate to the size of the tile into which the branch discharges. For example, branches joining a .6-inch main should drop .2 ft., an 8-inch, .3, a 10-inch, .4, 12-inch, .5, and 15-inch, .7. To compute the starting-point for the branch line, add the drop to the grade-elevation of the main at the junction and proceed as before. Example: At Station $4 + 50$ (see notes), **Branch No. 1** is to have a .20 drop. The grade-line $98.35 + .20 = 98.55$ = elevation of grade-line at the outlet of the branch. This should be transferred to the notes of **Branch No. 1** and used as the initial point for computing the grade of that line.

Construction Figures. There are two methods of indicating the depths of cut at the several stakes for the use of the workman. They may be marked with a lead-pencil direct upon the guide-stakes, noting also

the points at which there is a change of grade. The workman then sets his guide-line and grades the ditch in accordance with the marks he finds upon the stakes. The more convenient and in many respects the better way is to prepare a tabulated statement in a small memorandum-book of pocket size which the workman or superintendent can use and keep for reference. This memorandum should give the depth at each stake, the grade, and size of tile to be used.

The following form will suggest to the engineer the manner of preparing the working figures:

DEPTHS OF DRAINS ON LIMESTONE FIELD

Main A				Branch No. 1			
Stake	Depth Ft.	Depth In.		Stake	Depth Ft.	Depth In.	
0	3	1	Grade 2-in. per 100 ft.	4	3	7	3-in. drop
1	2	8¾	8-in. tile	0	3	4	Grade 3-in. per 100 ft.
3	3	4¼		1	2	10	5-in. tile
3	4	0		2	2	9⅛	
4	3	7	Br. No. 1 enters in pond				
4+50	2	11		3	3	3⅜	
5	3	1		4	3	1½	
5+60	2	11½*	Br. No. 2 enters	4+60	2	11	End
6	2	10	* Grade 2½ in. per 100 ft.				

The Map. A complete map should be made after the field measurements have been finished. The value of full notes and sketches of the several divisions will now be appreciated, for from them a good working map for use in construction in connection with the specifications, as well as a permanent record of the drains,

can be made. The map should show the location of each drain, its outlet or its junction with another line, its total length, which should be placed at the end, the number and size of the tile required, the location of all surface-inlets, silt-basins, etc. It is also well to record the grade of the drains from point to point, and the surface elevations at various representative places throughout the tract.

It should be remembered that the map is made to record information relating to the drainage of the tract represented in a comprehensive and compact form. **Figs. 22 and 23** show sections of a map each delineating a

TABLE I

Decimals of a Foot Reduced to Inches

Foot	Ins.	Foot	Ins.	Foot	Ins.	Foot	Ins.	Foot	Ins.
.0104	⅛	.2188	2⅝	.4271	5⅛	.6354	7⅝	.8438	10⅛
.0208	¼	.2292	¾	.4375	¼	.6458	¾	.8542	¼
.0313	⅜	.2396	⅞	.4479	⅜	.6563	⅞	.8646	⅜
.0417	½	.2500	3	.4583	½	.6667	8	.8750	½
.0521	⅝	.2604	⅛	.4688	⅝	.6771	⅛	.8854	⅝
.0625	¾	.2708	¼	.4792	¾	.6875	¼	.8958	¾
.0729	⅞	.2813	⅜	.4896	⅞	.6979	⅜	.9063	⅞
.0833	1	.2917	½	.5000	6	.7083	½	.9167	11
.0938	⅛	.3021	⅝	.5104	⅛	.7188	⅝	.9271	⅛
.1042	¼	.3125	¾	.5208	¼	.7292	¾	.9375	¼
.1146	⅜	.3229	⅞	.5313	⅜	.7396	⅞	.9479	⅜
.1250	½	.3333	4	.5417	½	.7500	9	.9583	½
.1354	⅝	.3438	⅛	.5521	⅝	.7604	⅛	.9688	⅝
.1458	¾	.3542	¼	.5625	¾	.7708	¼	.9792	¾
.1563	⅞	.3646	⅜	.5729	⅞	.7813	⅜	.9896	⅞
.1667	2	.3750	½	.5833	7	.7917	½	1.00	12
.1771	⅛	.3854	⅝	.5938	⅛	.8021	⅝		
.1875	¼	.3958	¾	.6042	¼	.8125	¾		
.1979	⅜	.4063	⅞	.6146	⅜	.8229	⅞		
.2083	½	.4167	5	.6250	½	.8333	10		

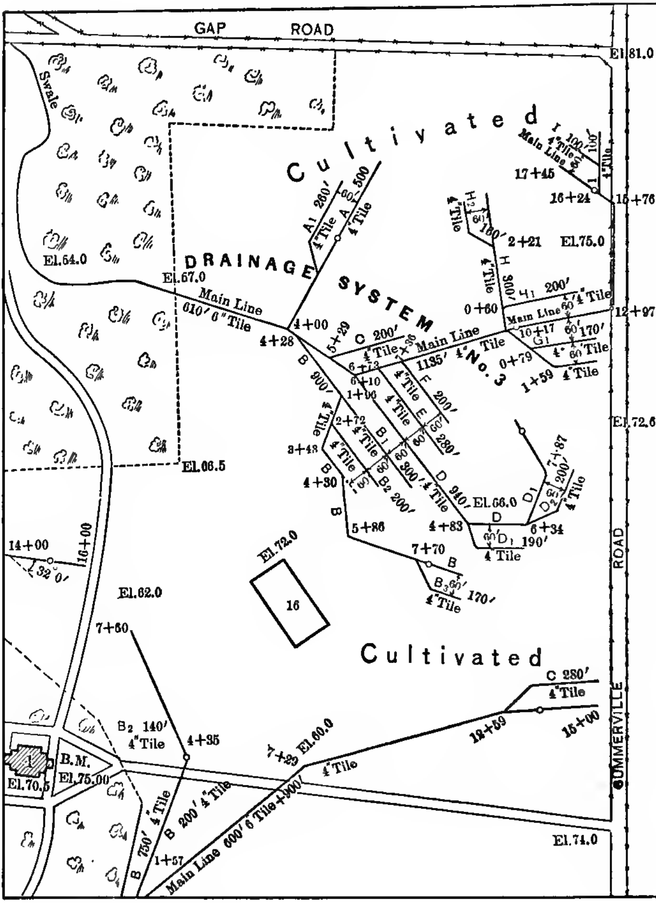


FIG. 22.—SECTION OF FARM DRAINAGE MAP, NO. 1.
From files of Drainage Investigations U. S. Dept. of Agriculture.

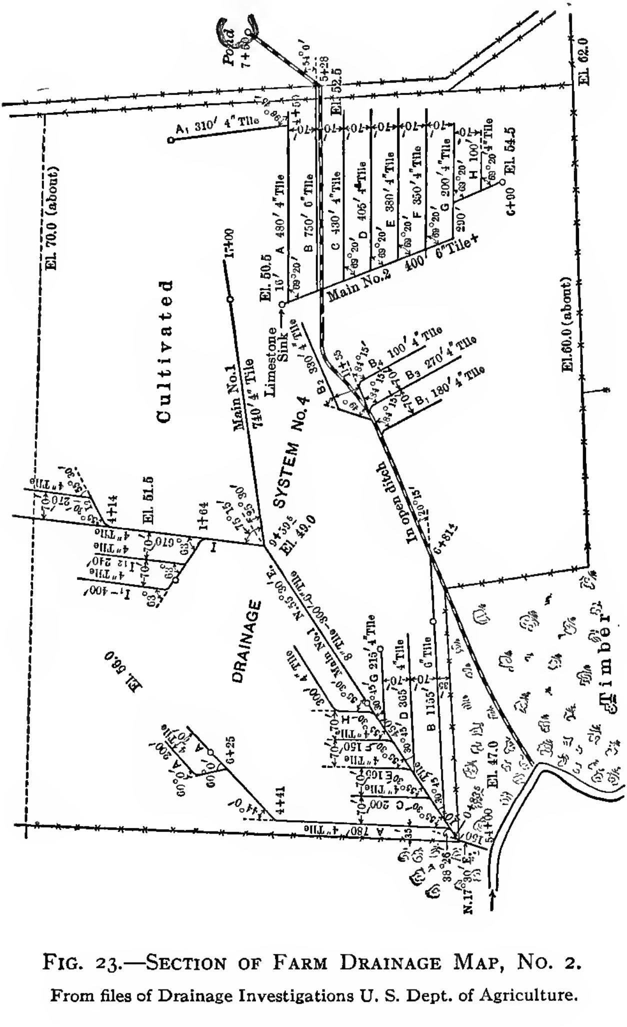


FIG. 23.—SECTION OF FARM DRAINAGE MAP, NO. 2.

From files of Drainage Investigations U. S. Dept. of Agriculture.

different system on a single plantation. The entire map has a title and explanatory notes such as are described in Chapter III. The figures also illustrate the use of the different systems or arrangements of drains to meet the conditions of the land.

Reduction Table. For convenience in reducing the decimal expressed in the cut, or depth, column of the notes to inches and fractions of an inch, which will usually be demanded by workmen when digging the ditches, a table is here given. In all engineering computations it is desirable to use the decimal scale, but the engineer will soon learn the equivalents of decimals of a foot in inches and fractions, so that he can write them without referring to the table. Reductions to the nearest ⅛ inch are sufficiently close for use in constructing ditches. (See Table I, page 89.)

CHAPTER VII

FLOW IN UNDERDRAINS

THAT the engineer may determine the size and number of drains which shall be adequate for any system of drainage, it is necessary that he understand and be able to apply the principles governing flow of water.

Elaborate experiments and painstaking investigations have been made by eminent hydraulicians on the flow of water through pipes and channels, but only such results of their work as have a bearing upon drainage problems need be discussed here.

Effect of Gravity. It should be borne in mind that gravity is the sole cause of flow of water, except when mechanical force is used. Gravity causes unsupported bodies to fall vertically, a ball to roll down an incline, and water to flow down hill or through an inclined pipe.

The formula used to express the theoretical velocity due to gravity in the case of falling bodies is:

$$v = \sqrt{2\,gh} \qquad \qquad (1)$$

where

v = velocity in feet per second,
g = accelerating force of gravity, = 32.2,
h = space through which the body falls.

It has been found by experiment that a body in vacuum at the level of the sea passes through a space of 16.1 feet during the first second, and at the end of that time has acquired a velocity of 32.2 feet. The velocity at the end of each succeeding second of time is 32.2 feet greater than it was at the end of the preceding second. This is called the accelerating force of gravity, and is desig-

nated in the formula by **g**. The following table shows at a glance the relation of time, space, velocity and accelerating force of gravity to a falling body during the first five seconds.

TABLE II

Falling Bodies During First Five Seconds

	1 Sec.	2 Sec.	3 Sec.	4 Sec.	5 Sec.
Space = h	16.1	64.4	144.9	257.6	402.5
Velocity = v	32.2	64.4	96.6	128.8	161.0
Accelerating force = g	32.2	32.2	32.2	32.2	32.2

Water flowing down an inclined surface would follow the same law were it not for resistances of various kinds which constantly act upon the particles of water as they descend and check their velocity, producing a more or less uniform flow. Were this not the case our ponds and lakes would soon empty themselves, and brooks and rivers would at times become dangerous torrents.

Velocity Formulas for Flow of Water. Many eminent experimenters have applied themselves industriously to the task of ascertaining the value of these retarding forces, and by the introduction of other factors into the gravity formula so modifying it that it shall be a correct expression for the flow of water under known conditions of channel, and thus make it of use in practical affairs. Simple as the problem may seem at first, it has occupied the time and thought of these hydraulicians for many years, and they are justly noted for their researches in this department of practical science. The results of their labors are a number of velocity formulas which bear the names of those who developed them and which have been found to be reasonably correct for the conditions under which the researches were conducted. Thus we have the formulas of Prony, Du Buat, Weisbach,

Bazin, D'Aubuison, Beardmore, Chezy, Darcy, Poncelet, Neville, Eytelwein, Kutter and others, all of which have been used by engineers with more or less confidence. Such formulas are essential in the work of engineers, and their value depends upon the nearness to which the results they give approach the actual measured velocity of flow. When we consider the great variety of conditions which affect the flow of water we can easily appreciate the difficulty of developing a formula of general application.

When the flow of water through pipes is considered, the resistances to gravity are, first, resistance to the entrance of water into the pipe; second, the resistance offered by the walls of the pipe with which the water comes in contact. The first will vary with the kind of opening through which the water enters, the second with the roughness of the walls of the pipe, its length and diameter, and the number and size of bends. In the case of drain-tile laid in the soil, water enters the pipe through the spaces between the ends of the tiles, encountering a resistance dependent upon the size and roughness of the opening. The flow through the pipe is retarded by the roughness of the walls, bad joints, bends, the discharge from laterals, and sediment, if any exists.

The form of **Weisbach's formula** is such that the corrections which must be applied to the gravity formula so that it will express the velocity of flow in pipes are readily seen:

$$v = \frac{\sqrt{2gh}}{\sqrt{e + c \times \frac{l}{d}}} \quad \quad (2)$$

where

e = coefficient of resistance to entrance of water into pipe,
c = coefficient of friction of pipe,
l = length in feet,
d = diameter of pipe in feet

The numerator of the second member of the equation we recognize as the theoretical velocity of falling bodies (**Formula 1**); the denominator represents the resistances to flow through the pipe. We thus have the formula for falling bodies so modified that it will express the velocity of water in pipes.

There are other formulas, equally if not more accurate, which possess the very desirable excellence of greater simplicity. **Beardmore's** is one of the more simple formulas:

$$v = 100\sqrt{r\,s} \qquad (3)$$

where

$$r = \text{hydraulic mean depth, or hydraulic radius,}$$
$$= \frac{\text{area of waterway}}{\text{wet perimeter}} = \frac{a}{p}.$$
$$s = \text{sine of slope,}$$
$$= \frac{\text{head, or fall, in feet}}{\text{length of pipe}} = \frac{h}{l}.$$

Written in full, the formula is:

$$v = 100\sqrt{\frac{\text{cross sectional area}}{\text{wet perimeter}} \times \frac{\text{head}}{\text{length of pipe}}},$$

all dimensions being in feet.

The **Chezy formula** has the same form, but is more elastic:

$$v = c\sqrt{r\,s} \qquad (4)$$

This permits the substitution of different values for c, expressing variations in the resistance, making the formula adaptable to a wider range of conditions than when a fixed value is used as in Beardmore's formula.

The foregoing expressions are given to show the derivation of velocity formulas which are used by engineers in computing the flow of water through continuous pipes, sewers and conduits of various kinds when the

head of water is known and the pipes come within reasonable limits of perfection in workmanship. When the velocity is found, the discharge is obtained by multiplying the area of the column, or stream, of water expressed in square feet by the velocity in feet per second. The result will be the discharge in cubic feet per second.

This is expressed by formula as follows:

$$Q = a\,v, \quad \ldots\ldots\ldots \quad (5)$$

where

Q = quantity in cubic feet per second,
a = area of column of flowing water in square feet,
v = velocity determined by formula.

Then the relation between discharge, area, and velocity are:

$$v = \frac{Q}{a}$$

$$a = \frac{Q}{v}$$

Then for discharge, Beardmore's formula becomes:

$$Q = 100\,a\sqrt{r\,s} \quad \ldots\ldots\ldots \quad (6)$$

and Chezy's,

$$Q = a\,c\sqrt{r\,s} \quad \ldots\ldots\ldots \quad (7)$$

This is sufficient discussion to direct attention to the several factors that must be recognized in constructing a formula that will correctly represent the flow of water in pipes.

Formulas for Flow in Tile Drains and Their Use. Flow through a pipe is not uniform in different parts of its diameter. Measurements show that the velocity is least at the circumference and that it increases toward the center. Concentric rings within the pipe have approximately equal velocity, but such rings are not always circles, showing that in the best constructed and laid pipes there are internal eddies which disturb the regu-

larity of flow. Experiments also establish the fact that in pipes, especially tile drains and sewers, velocity is not uniform in different lengths of a drain which has the same diameter and gradient. Formulas represent the mean velocity of flow, that is, a velocity which multiplied by the area of the pipe will correctly express the rate of discharge. The elements which produce and control the flow are the gradient or head, the degree of roughness of the walls of the conduit and its cross-sectional area. Formulas express the law of flow when these factors are known and the water is supplied to the pipe.

The application of a velocity formula to tile drains in such a way as to be useful in the design of under-drainage systems, is subject to some difficulties which will be here discussed. A tile drain is a continuous pipe made up of sections one, two, or three feet long, with small spaces between them through which water enters. When the soil surrounding the pipe is saturated, water enters all parts of the joint along the entire line, pressing into the pipe with a weight the amount of which depends upon the openness of the soil and consequent freeness with which water passes through it. When the soil is saturated, with occasionally free water on top, a condition which occurs when drains are called upon to perform their maximum duty, water flows through the drain with a velocity due not only to the slope of the drain, but to the head added by the soil water above the drain, equal to the weight of free water less the resistance offered by the intervening particles of earth. The practical effectiveness of this head has been proven where tile drains have been laid in open soils upon a level gradient but with free outlet. A liberal discharge takes place with no head to produce flow except the water above the tile. Soil water head diminishes in

proportion to the closeness of the soil, becoming nearly zero in tight clay soils.

Another hydraulic condition peculiar to tile drains is that in any extended system, a series of submains and laterals furnish a flow to the main drains through pipes which usually have a greater fall than the main, or in any event have a drop at the point of discharge so that the entire lateral system occupies a higher level than the main drain and when full and in operation adds to the effective head of the main and accelerates its flow. The effect of such a condition is seen where the lateral system on one side of a main occupies a higher level, and has drains with greater slope than the opposite corresponding side. The discharge from the low level drains is held back until the flush flow from the drains with heavier gradient has passed. Another instance of not infrequent occurrence, is that of a large main tile laid upon a light grade to serve as an outlet for a large number of laterals. When operating under conditions of maximum flow the water "shoots" from the tile with much greater velocity than that due to slope upon which it is laid, showing that it derives an added head from the laterals which discharge into it.

A tile drain under certain conditions of saturated soil which surrounds it may become a mere conduit through which water may be forced by a supply which is brought to it from a higher level. The so-called "raised outlets," quite commonly used in the earlier tile drain practice, depend for their operation upon the ability of a drain passing through a saturated soil to withstand the pressure of water flowing under a considerable head.

The foregoing conditions peculiar to tile drains make it impracticable to apply the accepted formulas for velocity in pipes to the design of tile drainage systems

without certain modifications which will take those conditions into account. Many rules and formulas which have been prepared by engineers for this work, since the tile drainage has come into prominent notice, have been discarded by practical drainers because they failed to give the results that were obtained in actual practice. The formulas were not sufficiently flexible to meet the hydraulic conditions under which drains operate.

Another condition modifying flow in tile drains is the roughness and irregular alignment of the conduit as commonly constructed. These retarding forces must be represented in the formula by appropriate variable factors if reliance is to be placed upon the results it gives. The perfection of workmanship in constructing the drain has a greater effect on flow than is usually suspected. Careful measurements made by students of an Iowa State College, Ames, Iowa,* demonstrated that certain large tile well laid discharged 8 per cent more than the same size and kind of pipe which was laid in a more irregular manner, both, however, being commonly accepted as well-constructed drains. This confirms what has been found true in practical work as to the effect which the condition of the conduit has upon its discharge, and emphasizes forcibly the fact that good workmanship even to the extent of overexactness will materially increase the carrying capacity of a drain.

European engineers, particularly those of France and Germany, have examined this phase of the subject quite fully in an attempt to develop a correct expression for flow in tile drains. Mr. L. Faure, General Inspector of Agricultural Improvements of France and author of "Faure's Drainage," in treating this subject says: "It is quite apparent that to express the flow of water

* Vol. 4, No. 5, Bulletin Iowa State College Experiment Station.

in tile, we should not take formulas that are applicable to ordinary conduits for tiles present numerous peculiarities." These he proceeds to note and further says, "During the early years which followed the introduction of drainage by tiles, engineers attempted to determine the diameter of drains by formulas used for the flow of water in ordinary conduits. As for example, Leclerc, in his 'Treatise on Drainage,' and Laffineur, in his 'Practical Guide to the Agricultural Engineer,' adopted for this calculation the **Darcy formula.**" After citing two formulas which for a time were favored by engineers, he says, "These formulas have been abandoned by the majority of engineers who now prefer the one proposed by Vincent, and which has been adopted by the General Commission of Silesia as well as by Perels, Gerhardt, and more recently by Nielsen."

The expression referred to has the form of the **Poncelet formula,** which the author has adapted for use in the design of tile drainage systems:

$$v = m\sqrt{\frac{d\,h}{l + 54\,d}} \quad \ldots\ldots\ldots \quad (8)$$

$$Q = a\,v$$

in which

v = **mean velocity in feet per second.**
d = **diameter of tile in feet.**
h = **head, or difference in elevation in feet between the extremities of the drain which is considered.**
l = **length of drain in feet.**
a = **area of tile in sq. feet.**
Q = **discharge in cubic feet per second.**
***m** = **coefficient dependent upon diameter of the tile.**

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*The original expression gives **m** = 48 for all diameters. It has been found that a given roughness of surface bears a greater proportion to the whole area of surface in a small pipe than in a large one. Hence **m** has different values for tiles of different diameters. The values given in the table coincide with those determined for drain tile.

Values for m

DIAMETER OF TILE		
Inches	Feet	m
5	.42	34
6	.50	36
8	.67	40
9	.75	43
10	.83	44
12	1.00	45
16	1.33	47
18	1.50	50
24	2.00	54
30	2.50	57
36	3.00	60
42	3.50	61
48	4.00	64

This formula applies to a well laid, straight drain, running full on a uniform gradient. It should be understood that h in the formula applies to head which is distributed so as to produce an even grade throughout the line. The values of the coefficient m represent the retarding effects of frictional resistance which is greater for small pipes than for large. For irregular shaped and badly laid tile, these values should be decreased as the judgment of the engineer may dictate.

Modifications of the Formula. The effective head under which a drain operates when discharging its maximum volume is the difference in elevation between the extremities of the section of the drain, which is under consideration, plus the weight of water in the soil above the drain. The latter is variable, depending upon the openness of the soil and the consequent freeness with which water percolates through it. The frictional resistance occasioned by the soil particles and by the joints of the drain absorb a large part and in many cases nearly all of the outside head. Nevertheless it is a tangible

and important factor in the discharge of drains, for it has been found that drains under conditions of maximum flow discharge a greater volume than is indicated by the ordinary formula. A factor may be introduced in the formula to represent the additional head, which would be a depth of water equal to a part of the depth of the soil above the drain. Representing this depth as **k**, we may add to **h** some fractional part of **k**, as .5 or .3, to obtain the total head which should be used. The formula would then become:

$$v = m\sqrt{\frac{d\,(h + .5\,k)}{l + 54\,d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The length of the drain to which the formula should be applied should be a representative part which is laid on the least grade. The value to be given to **k** is necessarily dependent upon the character of the soil. Its value would be large where surface inlets are introduced along the line.

Another factor which has even a greater effect upon the velocity of flow in a main drain, and in some cases requires a second modification of the formula, is the number of submains which discharge into it and the fall they have compared with that of the main. If they have a grade about the same as the main or receiving drain, no additional velocity will be imparted. But if the drains which feed it have a greater grade or are laid upon a higher level, the velocity of flow will be increased by reason of the head of such drains which connect directly with the main. The branches comprising a system of drains when full of water may be regarded as a series of small reservoirs which are connected with the main drain and by their pressure add to the velocity of its flow. The head provided by such submains, or by the upper part of the main when it has a large fall, converts

the lower reach of the drain into a pipe which flows under pressure. Under such conditions soil water is prevented from direct entrance into the main, unless it is of ample size, until the flood supply of field drainage water is reduced.

The head of a main with submains which have a greater rate of fall than the main would be h plus the average additional head supplied by the submains. Let b represent the sum of the differences between the head of the main and that of the several submains and n the number of submains; then the total head will be:

$h + \frac{b}{n}$, in which

h = head of main,
b = sum of amounts in which head of submains exceeds that of main,
n = number of submains.

The formula thus modified becomes:

$$v = m\sqrt{\frac{d\left(h + \frac{b}{n}\right)}{1 + 54\,d}} \qquad (10)$$

This increase of head should not be computed for the laterals which discharge into submains. The formula should be restricted to mains which have submains not less than six inches in diameter and connected with that section of the main drain whose capacity is being computed. Where extended systems of tile are used which require large and costly mains and submains, all of the factors which have been mentioned in the foregoing discussion should be given their proper place and weight as nearly as practicable. A close adherence by engineers in the design of drainage systems to hydraulic formulas, which have been found satisfactory for other purposes, has led to badly balanced designs and the

adoption of sizes of tile that have discouraged owners in the construction of drainage works. In some cases the plans of the engineer have been modified in the interest of economy but the changes have not always been in accord with sound practice. There is much room for the exercise of a trained judgment in the application and use of velocity formulas in drainage design. It is a matter of common observation that a tile drain of given size is more efficient under one condition than the same size of drain is under other conditions due to the causes which have been referred to in the foregoing discussions of the subject.

Examples:

FORMULA (8)

1. What is the velocity of flow at the outlet of a line of 12-inch tile running full, 1500 ft. long, laid on a grade of .20 ft. (2½ inches) per 100 ft.?

$$\left.\begin{aligned} d &= 1 \\ h &= 3. \\ l &= 1500 \\ m &= 45 \end{aligned}\right\} v = 45\sqrt{\frac{1 \times 3}{1554}} = 45\sqrt{.00193} = 1.91$$

2. For an 18-inch tile m = 50; v = 2.65
3. For a 24-inch tile m = 54; v = 3.29
4. What is the velocity of flow in an 8-inch tile running full, laid on a grade of .10 ft. (1¼ inches) per 100 ft., length 1600 ft.?

$$\left.\begin{aligned} d &= .666 \\ h &= 1.6 \\ l &= 1600 \\ m &= 40 \\ 54d &= 36 \end{aligned}\right\} v = 40\sqrt{\frac{.666 \times 1.6}{1636}} = 40\sqrt{.00066} = 1.00$$

FORMULA (9)

5. Taking the data given in example 1, but adding the condition that the drain is laid in a porous soil, such as peat-muck or open joint clay with 3 ft. of soil above the top of the tile, what will be the

maximum velocity when the soil is saturated along the entire length of the drain?

$$h = 3 + .5k = 4.5$$

$$v = 45\sqrt{\frac{1 \times 4.5}{1554}} = 45\sqrt{.00289} = 2.40$$

FORMULA (10)

6. An 18-inch main drain 2000 ft. long laid on a grade of .20 ft. per 100 ft. has 4 submains discharging at various points along its length. What will be the velocity of the main at the outlet, the submains being described as follows:

No. 1	1000	ft. long, grade	.30 ft. per 100
No. 2	1200	" " "	.25 " " "
No. 3	600	" " "	.50 " " "
No. 4	800	" " "	.40 " " "

No. 1	1000 ft. on grade of main	2.0 ft. submain	3.0	dif. ft.	1.0
No. 2	1200 " " " " "	2.4 " "	3.0	" "	.6
No. 3	600 " " " " "	1.2 " "	3.0	" "	1.8
No. 4	800 " " " " "	1.6 " "	2.20	" "	1.6
	Total				5.0

Thus $h = 4.0$, $b = 5.0$, $n = 4$;

substituting in formula, $4.0 + \frac{5.0}{4} = 5.0$ = actual head of main.

$$\left.\begin{aligned} d &= 1.5 \\ h &= 5.0 \\ l &= 2000 \\ m &= 50 \\ 54d &= 81 \end{aligned}\right\} \quad v = 50\sqrt{\frac{1.5 \times 5}{2081}} = 50\sqrt{.0036} = 3.0$$

CHAPTER VIII

THE RUNOFF FROM UNDERDRAINED AREAS

To determine the duty of a drain, or the quantity of water it will be required to discharge in a given time, is more difficult than to develop a formula which will express its carrying capacity. It is the office of a main drain to remove the water brought to it either by percolation through the soil, by a series of laterals, by such surface-inlets as may be provided, or by all these combined.

The measure of runoff which seems most rational, and which is now employed by drainage engineers, is a certain depth of water, in inches, which must be removed in 24 hours from the entire watershed to be drained. This amount is called the drainage coefficient of that area. Rainfall is measured and recorded in inches of depth; the fluctuations of the soil water-table and the amount of evaporation from the surface are measured by the same unit; the amount of water which is required to wet or irrigate a dry soil sufficiently to nourish vegetation is expressed in inches of depth; all of which suggest that the depth unit is the one most natural and convenient to use in drainage computations.

The formula for determining the number of acres a drain with a known discharge will serve is:

$$A = \frac{Q}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

in which

A = Acres which will be drained
Q = volume drain will discharge in sec.-ft.
c = quantity corresponding to drainage coefficient, taken from Table III.

To use this formula, divide the value of Q found by **Formula 8**, or a modification of it, by the number taken from **Table III**, which expresses the quantity of rainfall per acre or per square mile which it is desired to remove per second. The result will be the number of acres for which the drain will provide outlet. The coefficient should be selected from the table after consideration of locality, climate and rainfall. These will be discussed later on.

Drainage Coefficient of Underdrained Soils. No subject relating to drainage merits more careful consideration by the engineer than this. Tile-drainage systems were formerly employed only in draining fields of limited area, a system with a main 8 inches in diameter being looked upon as a large one. Now district systems often require main drains of pipe 36 inches in diameter. The determination of the economical size of the main, submains and laterals for such systems becomes a much more intricate problem than for the large field or medium-sized farm.

The conditions which affect the runoff from underdrained areas, be they large or small, are different in some respects from those attending the drainage of land by surface-ditches and natural watercourses. Underdrained soil is in a condition to receive water at every point where it falls, storing it beneath the surface instead of upon it, and later distributing the surplus to drains in its vicinity which are perfectly adapted to its removal. It will hold more water than one which is not drained, and in that way serves as a reservoir which regulates the flow to the mains, thus making their discharge more uniform. Such drainage prevents the massing or congestion of water on the surface which is so common on lands where open channels are depended upon. For these reasons the drainage co-

efficient for tile-drained lands is not as large as it is for those from which the runoff is removed by open channels, notwithstanding that tile-drained land is dried more quickly than that drained by open ditches.

Conditions Governing Runoff. The amount of runoff which should be provided for is governed by the following conditions:

First, by **the amount of rainfall in 24- and 48-hour periods.** The maximum monthly precipitation is usually a fair indication of large daily storms, but this is not always the case.

Second, by **the season of the year when the large precipitation occurs.** If it occurs during the winter or spring months, the runoff is larger than if the same amount falls during the summer months when evaporation and transpiration from plants is great.

Third, by **the openness of the soil** and the consequent quickness with which it will absorb the rainfall. An open soil will permit the water to reach the drains more rapidly than will a dense clay soil, and hence will require tiles of greater capacity, but the lines may be placed further apart.

The very quick and rapid removal of soil-water is not desirable in the drainage of farm land. The object should be to remove the surface-water quite quickly and secure a gradual movement of water through the soil into the drains. This movement is beneficial since fertilizing materials at the surface, both solid and gaseous, are lodged with the soil particles as the water percolates among them, and the air follows with its disintegrating effect upon the unweathered earth. For these reasons, sufficient drainage is better than too much.

The Drainage Coefficient a Variable. It is evident that the drainage coefficient for underdrained areas is a

variable, having different values for different sections and climates.

The government of the province of Silesia, Prussia, and also the French government, both of which exercise more or less authority in land-drainage operations, recommend for tile-drains a coefficient of .22 inch for level land and .29 inch for broken land. In Southern Germany, where experiments are conducted in draining moorland, water has been found flowing from tile-drain systems at the rate of ½ inch in 24 hours. Haarlem Lake, Holland, with an area of 43,000 acres, is drained by pumps which remove at times ⅜ of an inch in 24 hours. The annual rainfall ranges from 27 to 40 inches, the latter being the extreme. For the fens of Eastern England, whose drainage is dependent upon the fluctuations of the tide or upon the operation of pumps, a runoff of ¼ inch is now agreed upon by English engineers as the proper amount, and pump stations are designed upon that basis. The soil is absorptive, the main ditches have a fall of but a few inches per mile, and the annual rainfall is usually 22, rarely exceeding 27 inches. In Western England, where the annual precipitation reaches 50 inches, provision is made for removing ¾ inch in 24 hours.

The field drainage of Haarlem Lake and of the fens is principally accomplished by frequent open ditches which lead directly to the main ditches from which the water is pumped, but are comparable in some respects to tile-drained lands. The successful operation of drainage by pumps requires large reservoir capacity in the ditch system, in which the water is held until the pumps can remove it. From one-twentieth to one-thirtieth of the surface is usually occupied by ditches.

It is only in recent years that any attempt has been made in the United States to proportion the size of

main tile-drains by any method having a general application to a given section of country. The practice commonly followed has been to lay such sizes of drains as the judgment of the landowner or engineer might dictate, and replace them later with larger ones should they prove too small. But it has not infrequently been found that in such revision much larger tile than were necessary have been used in the attempt to avoid repeating the first error.

Examinations in Illinois and Iowa. In order to ascertain the capacity of tile-drains which are giving good service in the drained areas of Illinois and Iowa, and to arrive at a coefficient which will be adapted to similar lands, Drainage Investigations, of the U. S. Dept. of Agriculture, directed that a large number of systems be examined. The report of that work shows some interesting and valuable facts regarding the operation of large tile-drainage systems.*

Method employed. The capacity of the tile outlet of each system was computed by Formula 8, using the lower 1000 feet of length, the grade upon which that length was laid, and the diameter of the tile as quantities for substitution. The drainage coefficient shown is the depth of water, in inches, which would be removed in 24 hours from the entire area which was served by the main drain. The measure of thoroughness with which the lands were drained was ascertained from the farmers who owned and cultivated them.

Efficiency. The soil of the entire area is a black open loam with joint clay subsoil, and is noted for its ready response to underdrains. Lateral drains are placed from 100 to 250 feet apart for thorough field drainage.

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* Report of Drainage Investigations, U. S. Dept. of Agriculture, upon Runoff from drained Areas in Illinois and Iowa, 1908, by L. L. Hidinger.

RECORD NO. 1

Size of Tile Outlets in Livingston and Iroquois Counties, Illinois

System	Dia. of Tile, Ins.	Grade of Drain, Percent	Acres Drained	Drainage Coefficient, Ins.
A	24	.12	1040	.16
B	18	.07	400	.16
C	15	.05	400	.08
D	18	.10	480	.16
E	20	.05	1280	.053
F	22	.09	1020	.114
G	18	.17	680	.143

Systems A and B. Land formerly a level marsh with sandy subsoil; drains give satisfactory service.

System C. Drain much too small; will be removed and a larger tile used.

System D. Land somewhat rolling; tile has been in service a number of years, but is considered too small for that locality.

System E. This district is three miles long, the main drain being laid in the bottom of a surface-ditch which is maintained and serves as an overflow channel; the subsoil contains sand and gravel, the drain is considered satisfactory, though some of the landowners maintain that a larger one would be better.

System F. Drainage satisfactory.

System G. Drainage should be aided by shallow open trenches extended into ponds that collect water faster than it can be removed by the drain; the tile unaided by an overflow-ditch is not large enough.

We may conclude that a coefficient of .16 inch, or about 1/6 inch, proves sufficient in some of these lands, particularly those that are level and have open soils, but that in other cases the main tile-drain should have a

shallow overflow-ditch to aid in carrying more than usual precipitation. The inference is that ¼ inch will be ample for reasonably level lands of this class.

RECORD NO. 2

Size of Tile Outlets in Boone County, Iowa

No. of Drain	Dia. of Tile, Ins.	Grade of Drain Percent	Acres Drained	Drainage Coefficient Ins.
3	22	.05	560	.17
11	24	.13	1240	.14
15	12	.10	200	.14
16	28	.08	940	.22
18	22	.31	1040	.21
23	12	.12	150	.20
26	18	.20	500	.22
27	18	.50	600	.27

Efficiency. The land in this county is more undulating or rolling than that represented by the Illinois record.

Drain No. 3. This area is long and narrow, the main tile occupying the course of the open channel which formerly drained the district; drainage is considered satisfactory.

Drain No. 11. Tile considered too small; the plan of the engineer shows that an overflow-channel was to have been made and maintained, but this has not been done; land is rolling to such a degree that water runs quite quickly into ponds and depressions.

Drain No. 15. Land rolling and interior drainage not completed; overflow ditch recommended as a part of the plan, but not made; drainage not satisfactory.

Drain No. 16.. A part of the land is composed of peat, or muck, underlaid with clay, the balance black loam; drain is large enough.

Drain No. 18. This district is four miles long, but narrow; drain satisfactory.

Drain No. 23. Size of drain ample.

Drain No. 26. Drain is considered ample though lateral systems have not been constructed.

The results show that a drainage coefficient of $^1/_5$ or $^1/_6$ inch in connection with shallow overflow-ditches will give satisfactory drainage, and that $^1/_4$ inch will generally prove satisfactory, except where steep sloping land adjoining the ditches precipitates a surface-flow of water along the course of the drain.

Rainfall in Illinois and Iowa. The rainfall of these sections should be studied in connection with drainage records in order to apply the data to other sections.

RECORD NO. 3

Monthly Rainfall in Livingston County, Illinois. 1898-1907

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	No. Times Rain Exceeded 1 In. in 24 Hours
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
1898	3.80	2.07	6.64	2.95	6.12	3.79	0.29	3.35	4.86	4.42	2.50	1.26	42.05	14
1899	0.80	2.13	1.76	0.70	2.08	5.07	4.73	2.29	2.57	2.31	2.03	2.06	28.53	7
1900	1.76	4.50	2.87	1.09	3.72	2.99	4.49	5.03	1.99	1.69	3.35	0.42	33.90	No Record
1901	1.60	1.03	3.17	0.50	0.93	3.71	2.00	1.67	2.05	1.44	1.14	2.54	22.78	No Record
1902	0.44	1.43	3.82	2.10	5.72	11.53	7.52	3.62	5.36	2.09	3.11	1.49	48.23	No Record
1903	0.80	3.23	2.54	4.94	4.36	1.39	6.35	2.60	3.62	2.76	1.06	1.98	35.63	10
1904	3.92	1.84	5.73	3.63	2.67	1.95	5.37	2.45	5.79	0.17	0.06	2.14	35.72	8
1905	1.80	1.89	2.17	3.45	6.33	1.70	1.78	1.82	2.26	2.53	2.26	1.71	29.70	7
1906	3.07	1.78	3.28	2.18	1.77	2.35	2.39	0.80	3.56	1.61	2.58	2.62	27.99	5
1907	5.62	0.15	2.74	3.09	3.28	3.00	5.60	4.47	4.59	0.61	....	3.05	.....	No Record

Occasional rains amounting to 1.75 and even 2.30 inches occur in twenty-four hour periods.

RECORD NO. 4

Monthly Rainfall in Union County, Iowa. 1872-1908

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1871.....	....	1.99	....	....	.....	3.46	4.11	4.90	1.17	2.20	3.70	....	.....
1872.....	0.55	0.90	2.65	4.83	6.35	4.00	4.45	2.65	2.80	3.10	1.15	0.75	34.18
1873.....	0.85	0.79	0.60	3.10	3.55	3.75	3.45	0.60	2.95	1.25	0.30	2.15	23.24
1874.....	0.22	0.16	0.17	3.15	2.45	8.55	6.15	1.25	9.50	0.65	2.50	1.10	35.85
1875.....	0.50	1.70	1.95	1.00	1.80	8.55	9.70	2.95	8.35	2.00	0.20	2.70	41.40
1876.....	1.15	0.70	2.90	5.20	3.20	6.40	3.15	2.10	7.25	1.95	2.25	0.25	36.50
1877.....	1.15	0.55	1.75	4.30	5.50	6.25	2.50	2.55	1.85	4.00	1.46	1.80	33.66
1878.....	0.80	0.70	3.35	1.53	4.30	8.30	5.11	3.10	2.16	2.05	0.30	0.72	32.42
1879.....	0.80	0.85	0.55	2.05	....	....	....	....	....	....	....	....	.....
1880–93..	....	....	....	....	....	....	....	....	....	....	....	....	.....
1894.....	....	....	....	....	....	2.15	0.96	0.12	3.51	3.53	0.58	1.10	.....
1895.....	0.40	0.52	0.76	4.63	3.04	6.58	3.54	6.45	3.06	0.50	1.13	2.00	32.61
1896.....	0.50	1.09	2.34	3.67	6.85	3.00	9.10	7.15	4.94	3.93	1.06	0.53	44.16
1897.....	1.15	1.70	5.61	8.01	2.19	4.57	1.89	1.33	2.72	1.12	0.34	2.33	32.96
1898.....	1.75	1.51	2.07	2.38	4.25	5.76	2.67	0.59	3.29	3.03	2.24	0.69	29.23
1899.....	0.40	0.50	1.25	2.25	6.76	4.73	6.33	5.14	0.50	1.53	0.45	1.31	31.15
1900.....	0.23	1.51	2.52	3.39	4.42	2.02	5.67	4.59	5.96	6.90	1.11	0.25	38.57
1901.....	0.76	1.10	3.19	3.21	2.90	5.05	4.42	0.44	3.56	2.82	1.17	1.00	29.62
1902.....	1.30	0.40	0.71	1.85	7.31	4.88	8.67	5.80	7.32	4.32	1.90	2.30	46.76
1903.....	T.	0.96	0.71	1.45	11.90	2.97	2.83	12.34	3.38	1.96	0.88	0.20	39.58
1904.....	2.02	0.15	2.95	5.61	4.20	2.55	4.22	4.66	2.80	0.85	T.	2.30	32.31
1905.....	1.35	1.35	1.87	4.17	4.76	6.12	2.84	4.67	5.27	3.66	3.12	0.25	39.43
1906.....	0.40	1.00	2.21	4.25	2.97	2.11	1.76	3 63	2.43	1.48	1.90	1.85	25.99
1907.....	1.25	0.78	1.95	1.92	2.26	5.75	5.96	5.13	2.35	1.99	1.35	1.24	31.93
1908.....	0.60	1.48	1.64	1.23	8.69	5.90	3.52	5.21	0.76	6.55	2.02	0.35	37.95
Means...	0.82	0.97	1.99	3.33	4.75	4.93	4.48	3.80	3.82	2.62	1.35	1.24	34.10

Coefficient for Heavy or Dense Soils. With respect to more dense soils in localities which have about the same rainfall as those just described, it is observed that the lateral drains must be placed closer together in order to collect the water from the soil and deliver it to the mains, and that the water is absorbed by the soil less quickly. If the lateral drainage has been properly performed, the total amount removed will be approximately the same, but its discharge will be extended over a longer time. It is not found to be good practice, however, to use mains of less size on this account, as it is frequently advisable to admit water to the drains by surface-inlets, in which case a pipe of liberal size gives greater efficiency.

Some heavy soils found in the south, where the precipitation is greater than in the north, require the aid of surface-inlets or of overflow-ditches. Soils of a "gumbo" and "buck-shot" nature, by which is meant silty clays which are dense and sticky when wet, but exceedingly finely comminuted and tillable when exposed to sun and air, do not permit water to percolate through them readily. Drains placed from 40 to 80 feet apart, the distance depending on the amount of sandy material which is in the soil, will give good results on level lands. This is costly for lands used for field crops and often will be a sufficient reason, in the landowner's estimation, for not draining at all. A system of combined flat-ridging, surface-inlets and tile-drains gives very good service. The ridging consists of plowing the fields in strips, with the furrows running in the direction of the natural slope or the most practicable line of drainage. Lines of 4-inch or 5-inch tile are then laid about 2½ feet below the bottom of the dead furrows. The tile should be laid to an accurate grade. Drains laid 100 feet apart where the dead furrows are so graded

as to not let water stagnate in them will furnish very good drainage at a moderate cost. If the main drains are designed to carry a ½-inch runoff in sections where the annual rainfall is 50 inches, very good drainage will be secured. Surface-inlets need be provided only where there are depressions which are not reached by the surface-drains.

CHAPTER IX

SIZE OF TILE DRAINS

WITH the information contained in the discussions of flow and runoff in the two preceding chapters, the engineer should be able to determine such sizes of main drains as will be efficient and economical. Good judgment, however, must be exercised in selecting a drainage coefficient and in applying the rule or formula which shall assist the judgment in adjusting sizes to the requirements of the land. The engineer should become familiar with the factors which enter into the computations, and be able to use short methods of computing, in which tables play an important part. A few examples are here worked out and explanations given for the purpose of familiarizing him with the methods of work.

Application of Formulas. The method commonly used in applying the formulas is to assume a size of tile which in the judgment of the engineer will be correct, and compute its capacity. A formula so constructed as to give the diameter of the pipe direct is not convenient to use. Remembering that the capacities of pipes laid upon the same grade are to each other approximately as the squares of their diameters, the proper size can be readily fixed after one or two computations have been made. Advantage should be taken of the tables giving square roots, areas of pipes, etc.

Illustrative Examples. Given a farm of 160 acres. which is to be drained through one outlet. What size of tile should be used on the lower 1,000 feet of length which has a grade of .2 foot (2½ inches) per 100 feet, assuming a drainage coefficient of ¼ inch?

Volume to be removed = 160 × .0105 = 1.68 cu. ft. per sec.

Assume that a twelve-inch tile will be required, and use the formula,

$$v = m\sqrt{\frac{d\,h}{l + 54\,d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\begin{aligned} d &= 1 \text{ ft.} \\ h &= 2 \text{ ft.} \\ l &= 1000 \text{ ft.} \\ 54d &= 54 \text{ ft.} \\ a &= .7854 \text{ sq. ft.} \\ m &= 45 \\ Q &= a\,v \end{aligned}$$

Substituting values,

$$v = 45\sqrt{\frac{2}{1050}} = 1.95$$

$$Q = .7854 \times 1.95 = 1.53 \text{ cu. ft. per sec.}$$

Dividing the discharge by .0105, the drainage coefficient taken from Table III, we have,

$$A = \text{acres} = \frac{1.53}{.0105} = 146$$

With ½ inch coefficient

$$A = 73$$

Should the additional head furnished by the submains amount to one foot as would probably be the case,

$$v = 2.38 \qquad Q = .7854 \times 2.38 = 1.86$$

$$A = \frac{1.86}{.0105} = 177$$

It is assumed that the outlet is free. In a large system, local conditions as to head must be taken into account by the engineer and corresponding substitutions made in the formula.

A 6-inch tile drain, 1,500 feet long, is laid in an open soil on a grade of 3 inches per 100 feet at a general depth of 4 feet, there being 3.5 feet of soil above the top of the drain. With the proper number of branches of 4-inch tile, how many acres of farm land can be efficiently drained through it, the laterals being laid on the same grade as the main, and the drainage coefficient being ⅜ inch?

$$
\begin{aligned}
d &= .5 \text{ ft.} \\
h &= 3.75 + 1.75 = 5.50 \\
l &= 1527 \\
a &= .1964 \\
m &= 36 \\
\text{Dr. coef.} &= .0157 \quad \text{(Table III)}
\end{aligned}
$$

Substituting in Formula 9

$$v = 36\sqrt{\frac{.5 \times 5.50}{1527}} = 36\sqrt{.0018} = 1.52$$

$$Q = .1964 \times 1.52 = .296$$

$$A = \frac{.296}{.0157} = 19$$

A fair margin should be allowed in estimating sizes since the engineer may not be correct in his estimate of the effect of soil, topography and weather in their relations to drainage, nor that the material and methods of construction will conform to his specifications.

TABLE III

Cubic Feet per Second per Acre and per Square Mile that a Drain Must Discharge to Remove Various Depths of Water in 24 Hours

Depth in Inches.		Cu. Ft. per Sec.	
Fraction	Decimal	Per Acre	Per Sq. Mile
1	1.000	.0420	26.88
$\frac{15}{16}$	.938	.0394	25.20
$\frac{7}{8}$	.875	.0367	23.52
$\frac{13}{16}$	.812	.0341	21.84
$\frac{3}{4}$	.750	.0315	20.16
$\frac{11}{16}$	.688	.0289	18.48
$\frac{5}{8}$	.625	.0262	16.80
$\frac{9}{16}$	.562	.0236	15.12
$\frac{1}{2}$	.500	.0210	13.44
$\frac{7}{16}$	.438	.0184	11.76
$\frac{3}{8}$	.375	.0157	10.08
$\frac{5}{16}$	.312	.0131	8.40
$\frac{1}{4}$	.250	.0105	6.72
$\frac{3}{16}$	.188	.0079	5.04
$\frac{1}{8}$	.125	.0052	3.36
$\frac{1}{16}$	.062	.0026	1.68

Table III gives the cubic feet per second, per acre and per square mile, for various drainage coefficients from $\frac{1}{16}$ inch to 1 inch, expressed in common fractions and in decimals of an inch.

Tables for Estimating Sizes of Tile. The foregoing discussions, together with records from various sources regarding the performance of tile in drying land, show that set tables worked out by formulas based upon assumed premises and data can only serve as a general guide in designing the size of mains for underdrainage. The fact that tile drains of the same dimensions and theoretical capacity give varying results under different conditions, as measured by the effect they have upon the land, shows that such conditions should be examined and analyzed by the engineer in the application of formulas and tables.

Two tables of sizes of tile and the corresponding number of acres drained by them are here given. **Table IV A** has been computed on the basis of ¼-inch runoff for a length of 1,000 feet outlet section, the conditions being such that the tile flows full, and the outlet is not submerged above the top of the pipe. The latest corrected values of **m, Formula 8,** as scheduled on page 101, have been u ed. The ¼-inch drainage coefficient is generally applicable to localities where the annual rainfall does not exceed 38 inches. For localities having greater rainfall, reduce the number of acres by the following multipliers:

45	inches	.7
55	"	.6
60	"	.5

Table IV B has been computed by **Formula 9,** using a soilwater head in addition to the slope in computing the velocity. This table may be used in draining the

TABLE IV A

Acres Drained by Tile Mains

Computed with Discharge Due Only to Slope and with Tile Flowing Full. Drainage Coefficient ¼ Inch

Grade Per 100 Feet.		Diameter of Tile in Inches										
Ft.	Equiv In.	6	7	8	9	10	12	16	18	24	30	36
.04	½	9	15	21	31	41	66	138	197	434	790	1279
.05	⅝	11	16	24	34	45	73	156	221	482	884	1427
.08	1	12	20	30	43	51	93	197	278	614	1122	1810
.10	1 3/16	15	23	33	48	64	104	219	318	685	1255	2019
.12	1½	16	25	36	53	70	114	241	338	751	1368	2208
.16	2	19	28	42	61	81	133	278	394	869	1583	2558
.20	2⅜	21	32	48	69	91	147	311	457	970	1775	2858
.25	3	23	35	53	78	102	165	347	492	1082	1987	3200
.30	3⅝	26	39	58	84	119	180	380	538	1187	2175	3400
.40	4¾	30	45	67	97	128	208	439	623	1370	2505	4038
.50	6	33	51	74	108	144	233	490	667	1530	2800	4520
.75	9	40	63	92	133	175	285	601	852	1872	3416	5530

TABLE IV B

Acres Drained by Tile Mains

Computed with Discharge Due to Slope Plus Soilwater Head of 1.5 Feet. Tile Flowing Full. Drainage Coefficient ¼ inch

Grade per 100 Ft.		Diameter of Tile in Inches										
Ft.	Equiv. In.	6	7	8	9	10	12	16	18	24	30	36
.04	½	20	31	46	66	88	144	252	425	945	1730	2780
.05	⅝	21	32	48	69	91	147	311	442	970	1775	2858
.08	1	22	35	52	73	97	158	333	472	1042	1900	3065
.10	1 3/16	23	37	53	78	104	165	347	492	1113	1985	3195
.12	1½	24	38	55	80	105	171	360	512	1130	2080	3320
.16	2	26	40	59	85	113	183	386	548	1208	2202	3530
.20	2⅜	27	43	62	91	120	195	411	583	1280	2342	3780
.25	3	29	45	67	97	128	208	439	623	1370	2503	4038
.30	3⅝	32	47	71	103	136	221	467	660	1450	2658	4280
.40	4¾	34	52	79	114	150	244	516	730	1610	2940	4748
.50	6	38	56	86	123	163	265	556	794	1746	3197	5150
.75	9	44	69	101	145	192	312	658	934	2280	3759	6060

following kind of soils: Permeable and absorbent loams, joint clay loams, marly clays, peat mucks, timber mucks and other types with similar physical properties. The drains are expected to discharge their maximum volume under pressure, a condition which is not detrimental to lands for periods of short duration. These two tables represent limits between which most, if not all, soils in the humid belt will fall, with respect to their drainage requirements. While they express different results where uniformity might be expected, such variations come within the limit of successful drainage practice.

Illustrative Example. A 24-inch tile is laid on a grade of .10 feet per 100 feet and is one mile long. How many acres will it serve as an outlet, provided an adequate system of submains and laterals is connected with it, no allowance being made for additional soil-water or submain head?

Use Formula 8

$$d = 2 \text{ ft.}$$
$$h = 5.28 \text{ ft.}$$
$$l = 5280$$
$$54d = 108 \text{ ft.}$$
$$a = 3.142 \text{ sq. ft.}$$
$$m = 54$$

$$v = 54\sqrt{\frac{2 \times 5.28}{5388}} = 54\sqrt{.00196} = 2.39$$

$$Q = 2.39 \times 3.14 = 7.50$$

$$A = \frac{7.50}{.0105} = 714$$

Drainage areas requiring a 24-inch main will usually have a tributary system of submains and laterals or possibly surface inlets which will increase the head and

consequent discharge. Suppose that in the above example the lateral system under maximum water conditions should create an additional effective head of 2 feet, making $h = 7.28$ (Formula 9),

Then

$$v = 2.80 \qquad Q = 8.79 \qquad A = 836$$

Size of Laterals. The size of submains and laterals should not be fixed until the lines have been run out and the levels taken. If there are submains, estimate the area which will be drained by each and determine by formula or from a table the size at various controlling points, such as at the junction with the main or where the grades change in a marked manner. The sizes of the balance of the drains are adjusted to fit the conditions of the field as shown by the survey and by inspection of the land. Decrease the size of the tile up grade, unless the grade continues to flatten in that direction, in which case the same size may be continued farther up grade to compensate for decrease in slope.

No attempt should be made to have the capacity of the mains and submains equal to the combined capacity of the laterals, for the nature of the soil largely controls the distance apart, and hence the number of laterals. The character of the soil in two tracts may so differ that thorough drainage demands laterals 50 feet apart in one case, and 150 in the other, yet the runoff or discharge may be the same in both, requiring the same capacity of mains and submains. Ordinarily the laterals are required to carry but a small part of their full capacity, and the aeration thus afforded contributes to their value in the soil.

Should the system of laterals have a heavy grade as

compared with that of the mains or submains into which they discharge, the latter will operate under pressure when the rainfall is not very large, causing the water to flow with greater velocity than if the laterals of the system were laid on a flatter grade. This subject has been discussed in connection with formulas for flow. (**Chap. VII.**)

Limitations of Size, Grade and Length of Drain. The modifying factors in the operation of drains, which have been discussed, suggest what has been found true in practice, namely, that there are limits which should be placed upon the size, grade and length of drains and that these limits depend upon the condition of the lands through which the drains run. The minimum size of tile formerly used for laterals was 2-inch. No smaller than 3-inch is now advised and where grades are light, 4-inch tile are the smallest that should be laid for any purpose. Drains which pass through clay containing but little fine sand can be laid on a nearly level grade with no risk of silting up or filling, but in soils containing fine sand, a grade of 2½ inches or more, per 100 feet, should be secured, if possible, so that the tile will be self-cleaning. The friction in tile of the smaller sizes makes it necessary to limit their length. Beyond the size of 12-inch, however, the formulas for flow may be applied irrespective of the following empirical limitations. (See **Table V.**)

Tabulating Tile. After the engineer has determined the number and size of the tile for each drain, he should note them upon the field-book along with other particulars pertaining to the drain. The tile of the entire field, system or district should then be tabulated systematically, in order that a bill of tile according to size can conveniently be made out, and also that they may be distributed in the field without confusion.

TABLE V

Limit of Size of Tile to Grade and Length

Size of Tile in Inches	Minimum Grade in Feet per 100 Feet	Limit of Length in Feet
3	.10	800
4	.06	1,600
5	.06	2,000
6	.06	2,500
7	.06	2,800
8	.05	3,000
9	.05	3,500
10	.05	4,000
11	.04	4,500
12	.04	5,000

The form given below may be followed in making this list. The last column gives the total length of each separate drain and should be used in checking the work.

DISTRIBUTION OF TILE

(Example of Form)

Drain	12-in.	10-in.	8-in.	7-in.	6-in.	5-in.	4-in.	Total
Main A	800	1,200	250	450	200	1,300	480	4,680
No. 1							1,350	1,350
No. 2							1,100	1,100
No. 3							300	300
No. 4					350	450	900	1,700
Branch a of No. 4						900	600	1,500
No. 5						740	1,260	2,000
Main B			700		400	500		1,600
No. 1 of B						200	400	600
No. 2 of B							600	600
	800	1,200	950	450	950	4,090	6,990	15,430

Preliminary Estimate of Tile per Acre. Where a complete system of laterals placed at a uniform distance apart is contemplated, it is often desired to estimate roughly the number of feet of tile that will be required per acre. The following tabular statement will assist in making such an estimate. The length of mains required for the system must be added to the total for the entire tract:

20	feet	apart,	2,178	feet	per	acre.
25	"	"	1,742	"	"	"
30	"	"	1,452	"	"	"
33	"	"	1,320	"	"	"
40	"	"	1,089	"	"	"
50	"	"	872	"	"	"
66	"	"	660	"	"	"
80	"	"	545	"	"	"
100	"	"	436	"	"	"
150	"	"	291	"	"	"
200	"	"	218	"	"	"

Some helpful data and tables are inserted here for use in applying formulas and making computations.

CONVENIENT EQUIVALENTS IN MAKING COMPUTATIONS:

One acre	43,560 square feet
One acre foot	43,560 cubic feet
Water one inch deep on one acre	3,630 cubic feet
Water one inch deep on one square mile	2,323,200 cubic feet
One cubic foot of water weighs	62.4 pounds
One cubic foot of water =	7.48 gallons
One inch of water on one acre weighs	113.43 tons of 2000 pounds
Velocity of 1.466 feet per second =	1 mile per hour
Velocity of one foot per second =	.682 mile per hour
Cubic feet per second × 448.8 =	gallons per minute

TABLE VI
Square Roots of Numbers from .1 to 20
For Use with Formulas

No.	Sq. Rt.	No.	Sq. Rt.	No.	Sq. Rt.	No.	Sq. Rt.
.1	.316	.8	1.673	.4	2.720	12.	3.464
.15	.387	.9	1.703	.5	2.739	.1	3.479
.2	.447	3.	1.732	.6	2.757	.2	3.493
.25	.500	.1	1.761	.7	2.775	.3	3.507
.3	.548	.2	1.789	.8	2.793	.4	3.521
.35	.592	.3	1.817	.9	2.811	.5	3.536
.4	.633	.4	1.844	8.	2.828	.6	3.550
.45	.671	.5	1.871	.1	2.846	.7	3.564
.5	.707	.6	1.897	.2	2.864	.8	3.578
.55	.742	.7	1.924	.3	2.881	.9	3.592
.6	.775	.8	1.949	.4	2.898	13.	3.606
.65	.806	.9	1.975	.5	2.915	.2	3.633
.7	.837	4.	2.	.6	2.933	.4	3.661
.75	.866	.1	2.025	.7	2.950	.6	3.688
.8	.894	.2	2.049	.8	2.966	.8	3.715
.85	.922	.3	2.074	.9	2.983	14.	3.742
.9	.949	.4	2.098	9.	3.	.2	3.768
.95	.975	.5	2.121	.1	3.017	.4	3.795
1.	1.000	.6	2.145	.2	3.033	.6	3.821
.05	1.025	.7	2.168	.3	3.050	.8	3.847
.1	1.049	.8	2.191	.4	3.066	15.	3.873
.15	1.072	.9	2.214	.5	3.082	.2	3.899
.2	1.095	5.	2.236	.6	3.098	.4	3.924
.25	1.118	.1	2.258	.7	3.114	.6	3.950
.3	1.140	.2	2.280	.8	3.130	.8	3.975
35	1.162	.3	2.302	.9	3.146	16.	4.
.4	1.183	.4	2.324	10.	3.162	.2	4.025
.45	1.204	.5	2.345	.1	3.178	.4	4.050
.5	1.225	.6	2.366	.2	3.194	.6	4.074
.55	1.245	.7	2.387	.3	3.209	.8	4.099
.6	1.265	.8	2.408	.4	3.225	17.	4.123
.65	1.285	.9	2.429	.5	3.240	.2	4.147
.7	1.304	6.	2.449	.6	3.256	.4	4.171
.75	1.323	.1	2.470	.7	3.271	.6	4.195
.8	1.342	.2	2.490	.8	3.286	.8	4.219
.85	1.360	.3	2.510	.9	3.302	18.	4.243
.9	1.378	.4	2.530	11.	3.317	.2	4.266
.95	1.396	.5	2.550	.1	3.332	.4	4.290
2.	1.414	.6	2.569	.2	3.347	.6	4.313
.1	1.449	.7	2.588	.3	3.362	.8	4.336
.2	1.483	.8	2.608	.4	3.376	19.	4.359
.3	1.517	.9	2.627	.5	3.391	.2	4.382
.4	1.549	7.	2.646	.6	3.406	.4	4.405
.5	1.581	.1	2.665	.7	3.421	.6	4.427
.6	1.612	.2	2.683	.8	3.435	.8	4.450
.7	1.643	.3	2.702	.9	3.450	20.	4.472

TABLE VII

Areas of Tile in Square Feet; also 54d
For Use with Formulas

Diam. in Ins.	Diam. in Ft.	Area in Sq. Ft.	54 d
2	.1667	.0218	9.00
3	.2500	.0491	13.50
4	.3333	.0873	18.00
5	.4167	.1363	22.50
6	.5000	.1964	27.00
7	.5833	.2673	31.50
8	.6667	.3491	36.00
9	.7500	.4418	40.50
10	.8333	.5454	45.00
11	.9167	.6600	49.50
12	1 foot	.7854	54.00
13	1.083	.9218	58.50
14	1.167	1.069	63.00
15	1.250	1.227	67.50
16	1.333	1.396	72.00
17	1.417	1.576	76.50
18	1.500	1.767	81.00
19	1.583	1.969	85.50
20	1.667	2.182	90.00
21	1.750	2.405	94.50
22	1.833	2.640	99.00
23	1.917	2.885	103.50
24	2 feet	3.142	108.00
25	2.083	3.409	112.50
26	2.166	3.687	117.00
27	2.250	3.976	121.50
28	2.333	4.276	126.00
29	2.416	4.587	130.50
30	2.500	4.909	135.00
31	2.584	5.241	139.50
32	2.666	5.585	144.00
33	2.750	5.940	148.50
34	2.834	6.305	153.00
35	2.916	6.681	157.50
36	3 feet	7.069	162.00

TABLE VIII

Head in Inches Reduced to Feet

For Use with Formulas

Head in Ins. per 100 Ft.	Head in Ft. per 100 Ft.	Head in Ft. per Mile	Head in Ins. per 100 Ft.	Head in Ft. per 100 Ft.	Head in Ft. per Mile
1/16	.0052	.274	3		
1/8	.0104	.549	1/8	.2604	13.749
1/4	.0208	1.098	1/4	.2708	14.298
3/8	.0313	1.652	3/8	.2813	14.852
1/2	.0417	2.201	1/2	.2917	15.401
5/8	.0521	2.750	5/8	.3021	15.950
3/4	.0625	3.300	3/4	.3125	16.500
7/8	.0729	3.849	7/8	.3229	17.049
1	.0833	4.398	4	.3333	17.598
1/8	.0938	4.952	1/8	.3438	18.153
1/4	.1042	5.501	1/4	.3542	18.702
3/8	.1146	6.050	3/8	.3646	19.251
1/2	.1250	6.600	1/2	.3750	19.800
5/8	.1354	7.149	5/8	.3854	20.349
3/4	.1458	7.698	3/4	.3958	20.898
7/8	.1563	8.252	7/8	.4063	21.453
2	.1667	8.801	5	.4167	22.002
1/8	.1771	9.350	1/8	.4271	22.551
1/4	.1875	9.900	1/4	.4375	23.100
3/8	.1979	10.449	3/8	.4479	23.649
1/2	.2083	10.998	1/2	.4583	24.198
5/8	.2188	11.552	5/8	.4688	24.753
3/4	.2292	12.101	3/4	.4792	25.302
7/8	.2396	12.650	7/8	.4896	25.851
3	.2500	13.200	6	.5000	26.400

TABLE IX.—Table of Feet in Decimals of a Mile

Miles	0.000 Ft.	0.001 Ft.	0.002 Ft.	0.003 Ft.	0.004 Ft.	0.005 Ft.	0.006 Ft.	0.007 Ft.	0.008 Ft.	0.009 Ft.
0.00	...	5	11	16	21	26	32	37	42	48
0.01	53	58	63	69	74	79	84	90	95	100
0.02	106	111	116	121	127	132	137	143	148	153
0.03	158	164	169	174	180	185	190	195	201	206
0.04	211	216	222	227	232	238	243	248	253	259
0.05	264	269	275	280	285	290	296	301	306	312
0.06	317	322	327	333	338	343	348	354	359	364
0.07	370	375	380	385	391	396	401	407	412	417
0.08	422	428	433	438	444	449	454	459	465	470
0.09	475	480	486	491	496	502	507	512	517	523
0.10	528	533	539	544	549	554	560	565	570	576
0.11	581	586	591	597	602	607	612	618	623	628
0.12	634	639	644	649	655	660	665	671	676	681
0.13	686	692	697	702	708	713	718	723	729	734
0.14	739	744	750	755	760	766	771	776	781	787
0.15	792	797	803	808	813	818	824	829	834	840
0.16	845	850	855	861	866	871	876	882	887	8[illegible]2
0.17	898	903	908	913	919	924	929	935	940	945
0.18	950	956	961	966	972	977	982	987	993	998
0.19	1003	1008	1014	1019	1024	1030	1035	1040	1045	1051
0.20	1056	1061	1067	1072	1077	1082	1088	1093	1098	1104
0.21	1109	1114	1119	1125	1130	1135	1140	1146	1151	1156
0.22	1162	1167	1172	1177	1183	1188	1193	1199	1204	1209
0.23	1214	1220	1225	1230	1236	1241	1246	1251	1257	1262
0.24	1267	1272	1278	1283	1288	1294	1299	1304	1309	1315
0.25	1320	1325	1331	1336	1341	1346	1352	1357	1362	1368
0.26	1373	1378	1383	1389	1394	1399	1404	1410	1415	1420
0.27	1426	1431	1436	1441	1447	1452	1457	1463	1468	1473
0.28	1478	1484	1489	1494	1500	1505	1510	1515	1521	1526
0.29	1531	1536	1542	1547	1552	1558	1563	1568	1573	1579
0.30	1584	1589	1595	1600	1605	1610	1616	1621	1626	1632
0.31	1637	1642	1647	1653	1658	1663	1668	1674	1679	1684
0.32	1690	1695	1700	1705	1711	1716	1721	1727	1732	1737
0.33	1742	1748	1753	1758	1764	1769	1774	1779	1785	1790
0.34	1795	1800	1806	1811	1816	1822	1827	1832	1837	1843
0.35	1848	1853	1859	1864	1869	1874	1880	18[illegible]5	1890	1896
0.36	1901	1906	1911	1917	1922	1927	1932	1938	1943	1948
0.37	1954	1959	1964	1969	1975	1980	1985	1991	1996	2001
0.38	2006	2012	2017	2022	2028	2033	2038	2043	2049	2054
0.39	2059	2064	2070	2075	2080	2086	2091	2096	2101	2107
0.40	2112	2117	2123	2128	2133	2138	2144	2149	2154	2160
0.41	2165	2170	2175	2181	2186	2191	2196	2202	2207	2212
0.42	2218	2223	2228	2233	2239	2244	2249	2255	2260	2265
0.43	2270	2276	2281	2286	2292	2297	2302	2307	2313	2318
0.44	2323	2328	2334	2339	2344	2350	2355	2360	2365	2371
0.45	2376	2381	2387	2392	2397	2402	2408	2413	2418	2424
0.46	2429	2434	2439	2445	2450	2455	2460	2466	2471	2476
0.47	2482	2487	2492	2497	2503	2508	2513	2519	2524	2529
0.48	2534	2540	2545	2550	2556	2561	2566	2571	2577	2582
0.49	2587	2592	2598	2603	2608	2614	2619	2624	2629	2635

* Prepared by James G. Wishart.

TABLE IX.—Continued

Miles	0.000 Ft.	0.001 Ft.	0.002 Ft.	0.003 Ft.	0.004 Ft.	0.005 Ft.	0.006 Ft.	0.007 Ft.	0.008 Ft.	0.009 Ft.
0.50	2640	2645	2651	2656	2661	2666	2672	2677	2682	2688
0.51	2693	2698	2703	2709	2714	2719	2724	2730	2735	2740
0.52	2746	2751	2756	2761	2767	2772	2777	2783	2788	2793
0.53	2798	2804	2809	2814	2820	2825	2830	2835	2841	2846
0.54	2851	2856	2862	2867	2872	2878	2883	2888	2893	2899
0.55	2904	2909	2915	2920	2925	2930	2936	2941	2946	2952
0.56	2957	2962	2967	2973	2978	2983	2988	2994	2999	3004
0.57	3010	3015	3020	3025	3031	3036	3041	3047	3052	3057
0.58	3062	3068	3073	3078	3084	3089	3094	3099	3105	3110
0.59	3115	3120	3126	3131	3136	3142	3147	3152	3157	3164
0.60	3168	3173	3179	3184	3189	3194	3200	3205	3210	3216
0.61	3221	3226	3231	3237	3242	3247	3252	3258	3263	3268
0.62	3274	3279	3284	3289	3295	3300	3305	3311	3316	3321
0.63	3326	3332	3337	3342	3348	3353	3358	3363	3369	3374
0.64	3379	3384	3390	3395	3400	3406	3411	3416	3421	3427
0.65	3432	3437	3443	3448	3453	3458	3464	3469	3474	3480
0.66	3485	3490	3495	3501	3506	3511	3516	3522	3527	3532
0.67	3538	3543	3548	3553	3559	3564	3569	3575	3580	3585
0.68	3590	3596	3601	3606	3612	3617	3622	3627	3633	3638
0.69	3643	3648	3654	3659	3664	3670	3675	3680	3685	3691
0.70	3696	3701	3707	3712	3717	3722	3728	3733	3738	3744
0.71	3749	3754	3759	3765	3770	3775	3780	3786	3791	3796
0.72	3802	3807	3812	3817	3823	3828	3833	3839	3844	3849
0.73	3854	3860	3865	3870	3876	3881	3886	3891	3897	3902
0.74	3907	3912	3918	3923	3928	3934	3939	3944	3949	3955
0.75	3960	3965	3971	3976	3981	3986	3992	3997	4002	4008
0.76	4013	4018	4023	4029	4034	4039	4044	4050	4055	4060
0.77	4066	4071	4076	4081	4087	4092	4097	4103	4108	4113
0.78	4118	4124	4129	4134	4140	4145	4150	4155	4161	4166
0.79	4171	4176	4182	4187	4192	4198	4203	4208	4213	4219
0.80	4224	4229	4235	4240	4245	4250	4256	4261	4266	4272
0.81	4277	4282	4287	4293	4298	4303	4308	4314	4319	4324
0.82	4330	4335	4340	4345	4351	4356	4361	4367	4372	4377
0.83	4382	4388	4393	4398	4404	4409	4414	4419	4425	4430
0.84	4435	4440	4446	4451	4456	4462	4467	4472	4477	4483
0.85	4488	4493	4499	4504	4509	4514	4520	4525	4530	4536
0.86	4541	4546	4551	4557	4562	4567	4572	4578	4583	4588
0.87	4594	4599	4604	4609	4615	4620	4625	4631	4636	4641
0.88	4646	4652	4657	4662	4668	4673	4678	4683	4689	4694
0.89	4699	4704	4710	4715	4720	4726	4731	4736	4741	4747
0.90	4752	4757	4763	4768	4773	4778	4784	4789	4794	4800
0.91	4805	4810	4815	4821	4826	4831	4836	4842	4947	4852
0.92	4858	4863	4868	4873	4879	4884	4889	4895	4900	4905
0.93	4910	4916	4921	4926	4932	4937	4942	4947	4953	4958
0.94	4963	4968	4974	4979	4984	4990	4995	5000	5005	5011
0.95	5016	5021	5027	5032	5037	5042	5048	5053	5058	5064
0.96	5069	5074	5079	5085	5090	5095	5100	5106	5111	5116
0.97	5122	5127	5132	5137	5143	5148	5153	5159	5164	5169
0.98	5174	5180	5185	5190	5196	5201	5206	5211	5217	5222
0.99	5227	5232	5238	5243	5248	5254	5259	5264	5269	5275

CHAPTER X

SELECTION OF DRAIN TILE

Two general classes of clay tiles are known as common clay tile and vitrified tile. **Common clay tile** are made from common brick clay which is sufficiently plastic to allow moulding easily and when well burned the quality is similar to a firm building brick. They are very generally used for land drainage, and tiles of this quality which have been in use for a hundred years or more attest their durability and efficiency for the purpose. They should give a clear ring when struck with a piece of iron or steel, should be round and reasonably symmetrical and straight. They are made in one-foot lengths up to 10-inch, above which size they are frequently made 18 to 24 inches long, and the very large ones 36 inches long. The degree of hardness varies greatly in ordinary tile, as does their ability to endure freezing and thawing when lying on the ground during the winter season in northern climates, or when exposed to the weather while in service, as are outlet tiles. Under such conditions many of them scale and crumble, but those which are placed in the ground while sound are durable and in every way satisfactory, provided they have been well burned.

It is not essential that the ends be true, since a little space between the tile is needed for the entrance of water. If the ends are slightly beveled, as they usually are, the separate pieces can be laid in a straight line and upon a true grade with a little space at the bottom of the joint, but with the top tightly closed.

Vitrified tile are made of ground shale or of a high grade clay, frequently mixed with common clay. This material will endure greater heat than the common clay and possesses elements that will fuse and form a hard mass which has greater strength and is less absorptive than tile made of common clay. The quality of such tile, however, varies greatly as the tests for resistance to crushing indicate that over-burning the ware may make it brittle and impair its strength. Care should be used in selecting tile for deep ditches. The tough and strong tile are those of medium burn and hardness, and are usually straight.

Second-class sewer pipe, with sockets, are frequently offered by manufacturers at prices which will warrant their use for drains. If the bad pieces are rejected they make excellent drains where large mains are needed, and the sockets often facilitate their use in making drains through soft material. If necessary, the joints for short distances can be cemented where especially unstable soil is encountered.

The sizes of tile are designated as 8-inch, 12-inch, 18-inch, etc., the numbers referring always to the inside diameter, regardless of the thickness of the walls. **Junction-tile** are made to facilitate connection of branches. These appear in two forms, known as Y's and T's. The former should always be used at the junction of two lines, having the stem joined to the main line at an angle between 45° and 60°. (Fig. 27.) T's are used only for connecting catch-basins and surface-inlets with drains. These junction-tile are valuable accessories, and should be purchased if possible, as the practice of making junctions of various kinds in the fields by chipping holes in straight tile is not to be recommended. Junctions are listed by manufacturers by naming the size of the main and its branch arm, as 6 x 4, which means a junc-

tion for connecting a 4-inch branch with a 6-in. main, or it is sometimes referred to as a 4-inch on a 6-inch, which is the clearer method of expression.

Curved tile, designated as one-eighth and one-quarter bends, are occasionally needed in the construction of large drains, but usually the curves in drains may be made so long that straight pipe can be used if the ends are slightly beveled by chipping. (Fig. 27.)

Large Tile. When tile 12-ins. to 36-ins. diam. are used for mains, they usually encounter conditions which are quite different from those met in field drainage. They are laid deeper and not infrequently pass through quicksand and other unstable earth which subjects them to great weight when the trench is filled with loose and liquid-like earth and when the earth at the sides of the trench is in a similar condition. Saturated earth weighs about 100 pounds per cubic foot, so that a pipe covered with earth to a depth of 8 feet would be required, when the soil is saturated, to support a pressure of 800 pounds per square foot, besides that upon the sides in case the earth were soft and unstable. The pressure, however, diminishes as the earth begins to dry, since it partly supports its own weight by the cohesion of its particles.

The large volume of water which flows through the larger pipes produces eddies at joints which are too large, or where there are imperfections in the alignment, and these sometimes cause the tiles to drop out of position. The latter should be sufficiently perfect to permit their being laid with as close joints as may be found necessary. The strength of large-sized tiles should be as great as that required for standard sewer pipe.

TABLE X

Specifications for Standard Sewer Pipe Adopted by Manufacturers East of the Illinois-Indiana State Line

Inside Diameter in Ins.	Thickness of Walls in Ins.
3 and 4	½
5 and 6	⅝
8	¾
9	13/16
10	⅞
12	1
15	1⅛
18	1¼
20	1⅜
22	1⅝
24	1¾

In sizes above 12-in. what are known as double-strength pipes are to be had, in which the walls are somewhat thicker in proportion to the diameter than in Standard pipe.

Tests of clay pipe of all classes show a wide range of resistance to crushing. The following tests of standard sewer-pipe bedded in sand, with weight applied to the entire length, shows the weight per foot of length at which they broke.*

8-inch	1,363 to 2,256	pounds
12 "	1,227 " 2,756	"
15 "	1,261 " 2,297	"
18 "	1,464 " 2,093	"

* From Folwell's "Sewerage."

RECORD NO. 5 *

Breaking Strength of Common Clay Tile

Tested by weights placed upon a platform resting on top of the tile; sides of tile unsupported

Length, Ins.	Diameter Ins.	Thickness of Walls, Ins.	Breaking, Pounds per Lin. Ft.	Remarks
24	12	1	1,287	Medium burned
24	12	1	1,168	" "
24	12	1	938	" "
24	15	1	1,032	" "
24	15	1	1,193	" "
12	6	5/8	990	" "
12	6	5/8	1,060	" "
12	6	5/8	815	Medium soft

* Tests by Albert Beymer, Rocky Ford, Colorado.

Relation of Absorptive Property and Strength. A general relation exists between the percent of water which a tile will absorb and its resistance to breaking when subjected to a uniform weight. Toughness, that is resistance to breakage from sudden blows or shocks incident to rough handling, is highly desirable. Some ware having low absorption is tender or brittle, while a comparatively soft and highly absorptive tile may be tough.

The following table has been compiled from laboratory experiments to determine the comparative absorptive properties of tiles and their resistance to crushing. The samples tested were taken from different factories and represent merchantable drain-tile.

The pieces were first thoroughly dried by being placed in a steam boiler room, and afterwards immersed in water for 72 hours. The amount of water absorbed

is given in percent of the weight of the dry tiles. The same tiles were tested for crushing strength in a laboratory testing machine. The pieces of tile were embedded in sand in a box which was furnished with a movable top, prepared for the purpose, and the weight was applied lengthwise along the top. The weight under which each piece broke is given in pounds per lineal inch of tile.

RECORD NO. 6 *

Amount of Absorption and Crushing Strength of Clay Tile

Samples 3 inches diameter, 12 inches long, with walls ⅜ inch thick

Number of Sample	Average Breaking Strength Pounds per Lin. In.	Average Percent Absorption	Remarks
1	276	6	Round
2	170	18	"
3	162	14	" soft
4	173	23.5	" "
5	161	19	" "
6	195	3.64	" glazed
7	154	5	4-in. hexagonal vitrified
8	279	1.2	3-in. " "
9	186	21.	Sole tile (flat bottom) soft
10	121	22.9	" " " " "

* Tests made by J. R. Haswell in laboratory of Cornell University, Ithaca, N. Y., 1909.

Since the samples were supported rigidly at the sides, the breaking test is much higher than it would be under tests as they are usually made, and the record is given here for comparison only. The tests show the great variation in the amount of water which tiles will absorb. The hard-burned ware absorb 2% to 6% of its dry weight of water, and the soft-burned, 14% to 23%.

The former broke under a load of 195 to 276 pounds per lineal inch, the latter under a load of 121 to 173 pounds. These results indicate that as a class hard-burned tiles are about 60% stronger than soft ones having the same thickness of walls. When subjected to reasonably uniform pressure tiles break lengthwise into four nearly equal pieces.

Porosity of Drain-Tile. Notwithstanding the large absorptive properties possessed by the softer grades of clay tile, water will not pass through their walls under the pressure to which they are subjected in the soil in sufficient quantity to be of any service in drainage. The term "porous tile" arises from the avidity with which dry tile will absorb water until it becomes saturated, but the water does not pass through in any appreciable quantity, being retained in the pores until removed by capillary action and by evaporation.

This fact was demonstrated as early as 1846 by Josiah Parkes, consulting engineer for the Royal Agricultural Society of England. He also attempted to secure greater permeability of the walls by having small holes pierced in them before drying. The clay quickly filled the holes after the tiles were placed in the ground, and Mr. Parkes concluded that the water which flowed from drain-tile entered them at the joints. This has been the subject of experiments at different times, and the conclusion has been reached, in every case, that the porous property in tile has no value for draining.

An experiment was made by Drainage Investigations, U. S. Department of Agriculture, under the direction of the author, in 1910, which illustrates this property fairly well. Two 6-inch and two 3-inch drain-tile made out of common brick clay, burned a salmon color, and as soft as are usually considered safe to use, were sealed at one end with cement mortar.

They were then immersed in water until they became saturated and afterward placed in a tank of water in which the surface was kept within a quarter of an inch of the top of the tiles. The tiles were covered so as to prevent any loss of water which percolated through the walls. The depth of water which accumulated in each of the tiles was measured at the end of four, twenty-four, forty-eight, and seventy-two hours, and the volume in cubic feet and gallons computed. The experiment was then reversed, the tiles being filled with water, and the amount which percolated through the walls collected in a saucer and measured. During this part of the experiment, the tiles were placed in a damp closet so that no water would be lost by evaporation. The results were as follows: Taking the average of the measurements, the four tiles showed a percolation of about .0049 cubic foot per square foot of surface in 24 hours. If an acre of ground were drained with lines of 6-in. tile of this quality, placed 50 feet apart, the total volume of water which would pass through the walls in 24 hours would be 6.92 cubic feet or 51.7 gallons. This is on the assumption that free water instead of saturated soil would surround the tile. If water entered only through the pores it would require 139 days to remove ¼ inch in depth of water from the acre, tiled in that manner, and 250 days if 3-in. tile of the kind experimented with were used. But drains so laid are capable of removing that volume of water from the soil in 24 hours.

These facts have been recognized for half a century by drainage engineers and by writers upon practical drainage, yet the porosity of tile as an important contributing factor in their use in draining land continues to be erroneously taught in agricultural literature, and occasionally by engineers who have only a theoretical knowledge of the subject.

Concrete Tile. The use of concrete for drain-tile has grown so rapidly during the last few years that it now occupies an important place in drainage works. Many expensive mistakes have been made in developing the manufacture of concrete, or cement, tile, and the occasional failures of imperfect pipe subject them to sharp criticism. The need of standard specifications upon quality of material and method of manufacture is appreciated by the drainage fraternity generally, and it is hoped that some standard which can be relied upon will soon be adopted. It is clear that first-class Portland cement and good sand should be used, and that they should be properly mixed. In order to obtain a dense, nonporous tile, the mixture should be wet, as opposed to what is known as "dry mixture." The proportion of 1 part good Portland cement to 3 parts of good sand, well mixed, produces a good tile. The practice is to make the walls somewhat thicker than those of clay tile, since the tests for strength generally show that cement tile are weaker than clay tile with equal thickness of walls. This, however, is a point not well established, as the results of tests vary greatly. The test for density is the ring which the pipe give when they are struck with a piece of steel.

In selecting concrete tile, the engineer should know the quality of the material used and the manner of making them. The value and stability of such tile depend so largely upon these two things, that both consumer and manufacturer feel the need of well-tested and standard methods which when used will insure tile of uniform and reliable quality. Abundant examples of tile now in service prove quite conclusively that well-made cement tile meet every requirement in drainage. Any failure of them indicates imperfections in their manufacture which need not have occurred.

The tendency of present drainage practice is toward the use of systems which require large tile outlets, sometimes placed at considerable depths. The requirements of drains under such conditions as far as strength is concerned are not definitely known, though experiments are being conducted at various points for the purpose of securing such information. In the meantime, the author advises that pipe twelve inches or more in diameter when placed at greater depths than four feet, be required to stand a test for crushing equal to that of ordinary standard sewer pipe, with the hope that standard specifications for the strength of both clay and cement drain-tile will soon be satisfactorily determined. Small tile for field use at ordinary depths are sufficiently strong if they sustain a weight of 800 pounds per lineal foot when the weight is placed along the medial line on top of the sample and the sides are unsupported.

CHAPTER XI

CONSTRUCTION OF TILE-DRAINS

THE engineer should be entrusted with the supervision, inspection, and acceptance of the work he lays out, and for that reason should be thoroughly versed in the details of grading ditches and tile-laying. If necessary he should instruct workmen regarding the essential points of the construction of underdrains. An apprenticeship of greater or less duration is required to develop a skilful drainer. The work is deservedly passing into the hands of those who by practice have acquired a proficiency which is readily acknowledged by those who appreciate superior work in draining. The engineer, however, may not be so fortunate as to secure such service, but be compelled to train new men to perform the work. The introduction of successful trenching machines has added an encouraging impetus to underdrainage, but whether the work is done by hand-labor or with the aid of power machines, the requirements of a well-laid tile-drain remain the same. For these reasons it is thought best to here describe the work in detail as the engineer may not have had the opportunity to inform himself fully upon the best practical methods of construction.

Grading. One of the most practical of the several methods of setting a guide for the workman in grading the bottom of the trench is **the line and gage method.** This consists in setting a line at a convenient distance above the surface so that it shall be parallel to the bottom of the required ditch. The position of the line is

shown in **Fig. 24.** If the ditch is 3 feet deep, the line **e** may be set 5 feet above the bottom. To do this, subtract the depth indicated for the ditch at the stakes **c** and **d** from 5 feet. The result will be the height above the grade-stakes that the line should be placed. It should be drawn tight and fastened as shown in the figure. If the distance between stakes is 100 feet, a support stake should be placed midway to prevent the line from sagging. The method of using the line is shown in **Fig. 25.** A gage-rod, **ab**, five feet long, or any other length according to the height at which it may be

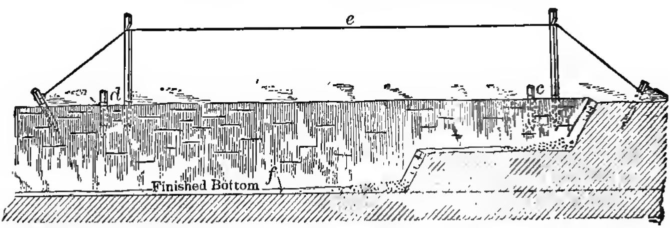


FIG. 24.—GUIDE-LINE FOR GRADING.

found convenient to set the line, is held vertically, with the under edge of the arm **b** touching the line **e.** The bottom of the ditch, **f**, is dressed down so that when tested by the gage the arm touches the line. In this manner the bottom can be graded so as to be exactly parallel with the line **e** and at the required depth. Each foot of ditch should be tested by the gage as the excavation proceeds.

Where excavation is performed by a machine which completes the ditch at one passage, guides are set in advance of the machine as shown in **Fig. 26**, where **a** represents the bar, or sighting point on the machine, which is at a fixed distance above the bottom of the finished ditch. The guide-arms, which may be adjust-

able on the standards **b**, **c** and **d**, are set the same distance above the proposed grade-line, their position being determined in the same manner as that described for setting the line **e** in the figure. As the machine moves forward toward the guides, the sighting-point, **a**, is made to coincide with the line of sight passing over two or more of the guide-bars, and the bottom of the ditch is finished parallel to the sight line **ae**, and according to the requirements of the survey.

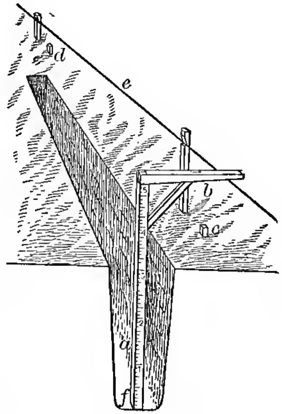


FIG. 25.—METHOD OF USING GRADE-LINE.

Excavating Trenches. The work should be started at the outlet and proceed up grade. The ditch should be started straight on the surface and the curves should be regular and neatly cut. To accomplish this the workman needs a ¼-inch rope which can be drawn tight along one side of the ditch or can be laid to form neat curves. The top width should be proportioned to the depth to which it is to be made, 10 inches being the minimum. A ditching spade with blade 18 or 20 inches long, slightly curved forward and straight across the cutting edge, or the same form of blade with longitudinal bars and a cutting edge instead of a solid piece, is used for all digging which does not require a pick and steel bar. The workman opens the ditch with the spade, using the cord, which has already been placed in position, as a guide. After taking out the first spading, the loose earth, of which a skilful workman will leave but little, should be removed with the long-handled

round-pointed steel shovel which is a part of the ditcher's outfit. If the ditch is about 3 feet deep, it can be excavated at two spadings, if 4 feet, three spadings will be required. The bottom is finished as the last spading is removed, care being taken not to let the spade penetrate deeper than the grade-line. The guide-line having been set, the cleaning-scoop is brought into use to

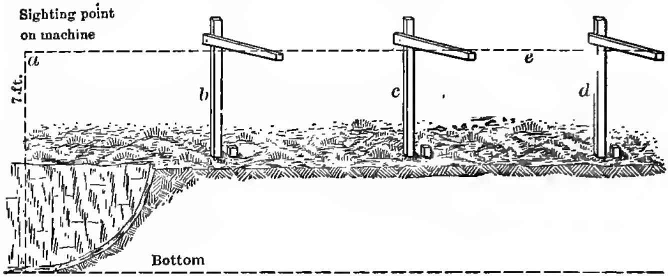


FIG. 26.—GUIDES FOR TRENCHING-MACHINE.

clean the loose earth from the bottom and bring it to an accurate grade. The workman stands upon the last bench and grades such a part as he can reach with the cleaning scoop, then opens more of the trench with the spade. The accuracy of the bottom is tested at any desired point by means of the gage, whose use is shown in Fig. 25. If the trench is large or the bottom hard and difficult to work with the scoop, the workman must make the trench wide enough to enable him to stand on the bottom and grade the bottom with the shovel. In any case, the bottom should be smooth and accurately graded. The importance of starting the top of the ditch straight will be appreciated when the bottom is reached, for it will there be found that the crooks at the top appear in more pronounced form. While the construction of large and deep ditches involves diffi-

culties peculiar to themselves, the principles relating to the preparation of the bottom will apply to all cases.

Laying the Tile. If the bottom has been well prepared, tile-laying, which should begin at the outlet, will be easily done. Sizes which can be conveniently handled may be laid with a tile-hook by the workman as he stands upon the surface. Some workmen prefer to place the tile in position with their hands while standing in the ditch. If the grading has been well done, the tile will fit the bottom perfectly and can be laid as accurately with the hook and with much more ease. The tile should be turned about until the ends fit closely

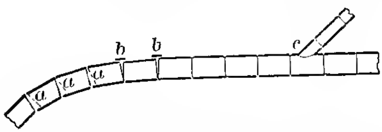


FIG. 27.—MAKING CURVES AND JUNCTIONS.

on top and the line is straight. Crooked and unshapely tile should be discarded, or if used at all, placed together at the upper end of the drain.

Necessary curves can often be made by using tile which are not quite square on the end; if such tile are not at hand the ends of other tile may be beveled slightly by chipping, or the convex portion of the curve can be left open and covered carefully with bats. These methods of making curves are shown at **aa** and **bb** in **Fig.** 27. Y junctions should be placed where needed, as shown at *c* in the figure, and the end of the Y securely closed with a piece of tile or a brick until the branch drain is constructed. As soon as the tile are laid the precaution should be taken to carefully place some moist earth on each side of them, tamping it slightly so as to fasten them securely in place.

Inspection. It may be well to here remind the engineer that a large amount of thought, labor and expense has been required in bringing about the construction of the drain. Its efficiency will depend largely upon the accuracy with which it is laid. Therefore before it is covered, and thus made a part of the land, it should be critically inspected, and even tested with the level. This can be done rapidly as follows: Set up the level and from a bench-mark, or from one of the station stakes, determine the H I. Begin at the outlet, testing the elevation of the outlet-tile. Let the rod-man pass up the line holding the rod on top of the tile at intervals of about 25 feet or at any point which he may think should be tested. Let the level-man record each reading and note if each successive one has the increment required by the grade. Some allowance should be made for variations in the diameter of tile, but these will be less than one might think if the tile are carefully laid. Any defects discovered in this way should be corrected and the tile then blinded by a covering of six inches of earth, after which the trench may be filled in any way that is found most expeditious.

Protection of Outlets. Every system of tile-drains must have a discharge through a main into some stream or large ditch. The banks of these watercourses are subject to erosion, and tile-outlets are subject to under-washing and displacement to such a degree that some permanent protection is needed for them.

In the first place, stoneware or vitrified pipe should be used at the outlet, as common clay pipe, which is serviceable when covered, will often crumble and decompose when exposed to the freezing and thawing which takes place at the outlet of a drain in cold climates. Hard sewerpipe, with sockets, make a superior outlet section if laid with cemented joints for a distance of

15 feet back from the point of discharge. In addition to this, a head-wall of stone or concrete should be made in such a way that the outlet-tile will be held in place and the bank be protected from washing away. Such structures are necessary, particularly where large tile are used, and must be substantially built. **Fig.** 28 shows a plan for a concrete structure suitable for such situations as are ordinarily encountered. **Fig.** 29 shows a bulkhead constructed of stone laid in cement mortar. The base rests two feet below the bottom of the ditch into which the tile discharges, and is two feet thick. If there is a surface-overflow from the land to provide for, the protection abutment should be extended in the form of a sluiceway. The backfilling about any wall should be thoroughly tamped. It is also well to protect the drain from the entrance of animals by the insertion of galvanized wires or small bars in front of the pipe in some way best suited to the structure.

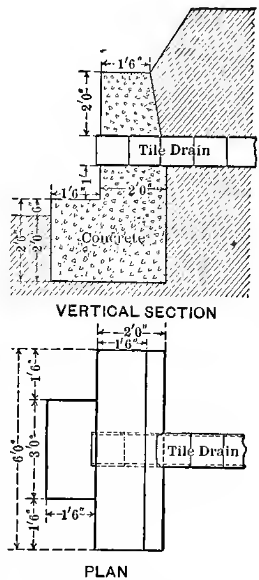


FIG. 28.—PLAN FOR CONCRETE OUTLET PROTECTION.

Surface Relief-Ditches. A pipe is not so elastic in capacity as an open ditch, and does not accommodate itself so readily to flood conditions. It is desirable to provide some relief so that the size of the tile may be restricted to the ordinary requirements of the land, and yet no serious injury be done by flooding during seasons

of more than usual precipitation. This may be accomplished by surface relief-ditches along the lines of the larger drains. Such drains often follow the course of former ditches so that small additional labor will be required in preparing them for service. If the large tile cuts across bends in the former ditch, the old water-course may, and should, be kept open unless the size of the tile is ample for the area to be drained. A relief-ditch of this kind should be broad and not deeper than two feet, if it is graded throughout so that there are no sinks to retain water. It should be so broad that it will offer no inconvenience in cultivating the land, nor prevent the planting and culture of crops in it. (**Fig. 30**). The office of such a ditch is to quickly remove a part of the excessive rains which occur occasionally and which would otherwise cause inconvenience and injury. After the excess is removed, the tile system operates in a most salutary manner and gives to the land the benefits which accrue from underdrains.

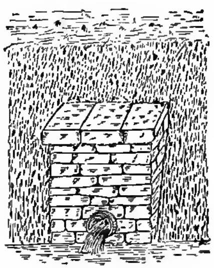


FIG. 29.—STONE BULKHEAD FOR TILE-DRAIN OUTLET.

Accessories. The efficiency of an all-tile drainage system for a large area, as, for instance, 800 to 2,500 acres, will depend largely upon the completeness of the lateral system. The entire area should be so well tiled that all rainfall will pass downward through the soil and the surplus be removed by drains. Under such conditions, the entire drained tract will be a reservoir which will be ready to receive and distribute water to growing plants and to the drains. As ordinarily managed, however, drainage district areas comprising a large number of farms will include combination systems,

so that various devices for facilitating the action of drains and securing the best land effects with the least outlay of labor and money must be planned by the engineer.

Surface-Inlets are useful accessories to tile-drains, and should be placed in depressions where water accumulates. They increase the free water-head to the

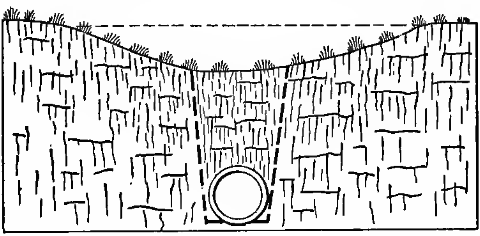


FIG. 30.—TILE-DRAIN WITH SURFACE RELIEF-DITCH.

drain, thereby accelerating the velocity of flow in it, because when the soil along the line is saturated, the tile will operate as a continuous pipe under pressure. The surface-inlet is also of special value in dense soils which do not permit water to move through them freely enough to fill the drain. This method of increasing the effectiveness of tile may be applied to all tile systems, provided proper precautions are taken to admit the water in such manner that debris and silt will be excluded.

Various devices are in successful use, the oldest and most easily constructed being a section of the trench filled with broken stone as shown in Fig. 31. A length of 3 to 6 feet of trench is filled with broken stone 3 or 4 inches in diameter or with cobble-stone of the same dimensions, the tile being laid with open joints on top. Two or more tile with T's may be used, the opening being loosely covered with stones.

Another form of inlet is made of sewer-pipe, 12 or 15 inches in diameter, on top of which a grate is placed, covered with stones to prevent debris from clogging it. (Fig. 32.) The pipe should be well set and the joints cemented. Inlets should be located where surface-water accumulates, and should be guarded by a fence so that the material will not be compacted by the tramping of livestock or disturbed by cultivating the land. If practicable, they should be located at fence-lines and other places where they may be easily protected.

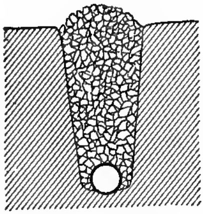


FIG. 31.—SURFACE-INLET OF BROKEN STONE.

A combined inlet and silt-basin constructed of sewer-pipe, as shown in Fig. 33, may be used in some locations to admit water direct. The inlet as shown should be guarded by a grating, and the silt which is carried into the basin and settles in the bottom, removed as often as necessary. The cover should be provided with a lock so that the basin cannot be opened by persons not authorized to do so. This form may be used on farm and public roads, yards, etc.

Silt-basins and Sand-traps are small wells placed at selected points along a single drain or at the junction of several drains to collect sand and silt and also to afford opportunity for inspection of the operation of the drains. The bottoms of the wells should be 2, and sometimes 3, feet below the tile which furnishes the outlet, to provide a receptacle for the deposit of silt. Water in passing through drops the sand it contains and flows

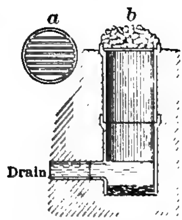


FIG. 32.—SEWER-PIPE INLET.

out through the tile on the opposite side. These accessories are not required in level lands with clay loam soils, but are useful wherever long drains are laid in sandy soils, or at those points in a drain where the grade, and, consequently, the water velocity, decreases, thus tending to deposit silt. They are best when made

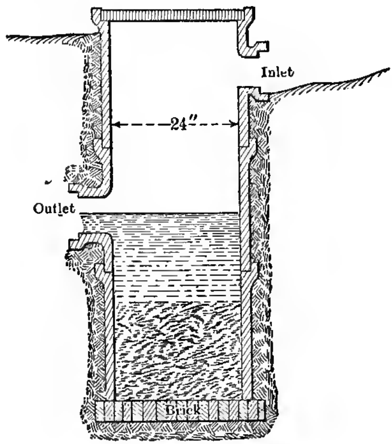


FIG. 33.—COMBINED INLET AND SILT-BASIN.

of brick, with a top constructed of heavy plank or of boiler-plate iron, which can be removed as often as desired for the purpose of inspecting the drains or taking out the deposit of sand. The box form of well, constructed of 2-in. plank and made 3 x 4 feet in section, serves the same purpose, but is less durable. (Fig. 34.)

Difficulties in Construction. The engineer is often consulted regarding difficulties which are encountered in constructing drains, and in his capacity as superintendent it becomes his duty to render the contractor such assistance as he can.

Of all difficulties which are encountered in constructing drains, quicksand, or any material that resembles it, is the most formidable to overcome. The resourcefulness of the engineer as well as the skill of the contractor and workman is often taxed to the utmost in such cases.

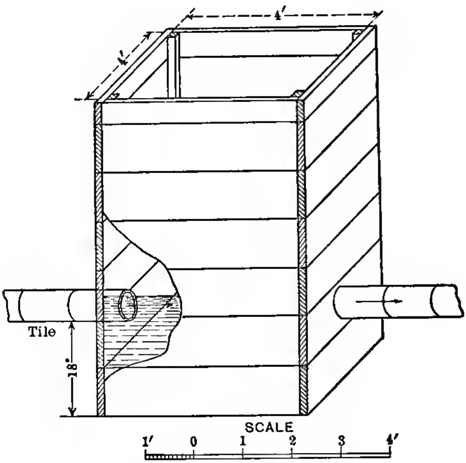


FIG. 34.—WOODEN SAND-TRAP.
(Farmers' Bulletin 371, U. S. Dept. Agriculture.)

If great expense is to be avoided, probably the most sensible plan is first to select a dry season of the year in which to excavate through soil known to contain quicksand, and, second, to lay the drain as far into the treacherous soil as can be done safely, and stop the work for a time until the quantity of water is lessened by gradual percolation, then proceed. It may take a month or two to pass through a bad place, but it will be safer and cheaper to proceed in this manner than to force the work through more rapidly. As an aid to solidifying the mass of unstable earth so that it

can be handled, temporary drains may be laid as far as possible, and above grade, in order to draw off surplus water.

In case quicksand is unexpectedly encountered and it is necessary to continue the work without interruptions, tight sheathing with strong braces must be resorted to. The sheathing planks of 2-inch material must be driven endwise as deep as the grade of the ditch, the excavation proceeding as the planks are driven down. The strength and frequency of the braces required will depend upon the condition of the earth. This method is slow and expensive, but is often required in constructing deep drains.

To prevent sand from entering the pipe at the joints, tarred paper, burlap, coarse hay or grass, or small bundles of fine twigs laid closely about the joints and covered with firm clay are always helpful. The best material for this purpose, however, is coarse gravel and should be used whenever it can be obtained. Sewer pipe with sockets are more easily laid in such earth than common tile. It is frequently necessary to place a board in the bottom of the trench upon which to support the pipe.

When there is risk of slumping or caving banks, the sheathing planks should be resorted to. In working under these difficulties every pipe should be tested for grade and alignment before it is passed. Some method for doing this should be devised by the engineer to suit the exigencies of the case.

During the construction of a drainage system, the work is often hindered in the spring of the year by heavy rains which fill the trenches that have been dug and submerge the lines of tile already laid. In the case of mains with light fall there is considerable risk from earth and silt which may be washed into the drain and par-

tially obstruct it. It is better to drive screen-stakes at the opening of the drain to prevent the entrance of coarse material and allow the flood to fill the tile, than to close the end and cause the entire volume to flow over the top of the drain.

Cleaning Tile-Drains. Notwithstanding that all possible care may have been taken to prevent mud and sand from entering tile during the construction of the drain, it frequently occurs that they will be found more or less obstructed from this cause. If the tile are in the required position, and are all right with the exception of the obstruction, do not disturb them but remove the material by one of the following suggested methods. Remove the earth from over the drain at intervals of twenty-five feet, exposing a length of about three feet at each place. Take out the tile and remove all silt that can be conveniently reached. If the tile are less than half full of mud and there is water enough in the pipe to make the material soft, place a bundle of stiff straw in a strong canvas sack of such size that it will partly fill the bore of the drain. Attach a rope securely to the sack and pass it through the drain from one opening to the other. This can be done by means of a set of jointed sewer rods which will be found useful in the various kinds of drain cleaning. The rods are made of wood one inch in diameter and 3½ feet long, provided with a loop at one end and a hook at the other, so shaped that they can be joined when placed at a right-angle to each other, but when opened out straight will remain fast together. The end of the rope may be pushed through the drain by the rods, length after length being attached until the rope is forced to the next opening in the drain. By means of the rope pull the swab through the drain, and as the material is forced to the opposite end let it be dipped or shoveled out. It is well to have a rope

attached to each end of the swab so that it can be drawn back and the operation reversed.

Instead of the canvas-bag swab, a metallic brush, which is constructed as follows, may be used. A wooden cylinder 4 feet long and of a diameter proportionate to the tile to be cleaned, serves as a center, or core, for the brush. A sheath of heavy leather, of a size to cover the core, is pierced with sharp-pointed steel wire nails with flat heads at about 3 inches apart. These are driven through the leather, which is then fastened securely to the core with the points of the nails outward. The nails are two, and for large tile, three inches long, and being adjustable by reason of the flexibility of the leather through which they are inserted, they accommodate themselves to the opening in the tile and at the same time loosen and push out the mud as the brush is drawn back and forth.

If the material in the tile is too solid to permit the use of the swab or brush, a small hinged spud or hoe may be made and operated by using the jointed rods as a handle. The hoe should be about 3 inches square and have a hinge joint which will permit it to close when the tool is thrust into the mud and open as it is pulled back. This loosens the mud and also enables the workman to pull it to the opening. Care should be taken in replacing the tile to preserve the original alignment. A little mud or sand will always remain in the drain after it has been scoured in this way, but it will be readily washed out when the drain is flushed, provided the latter is otherwise in perfect condition. It will be wise to construct occasional sand-traps on portions of the line where it is suspected that sand will interfere with the operation of the drain.

Specifications and Contracts. It is usually desirable to have large drainage systems constructed by contract.

There are four divisions of the work: Furnishing the tile on the cars at the nearest railway station; hauling them from the station and distributing them upon the ground ready for use; digging the ditches and laying the tile; and back-filling the trenches. Tile are purchased at a rate per 1,000 feet. They are hauled from the station or factory and distributed on the ground at a price per ton of 2,000 pounds, the weight of the individual pieces of different sizes being used as a basis for determining the weight of the loads. Digging ditches and placing the tile in position are commonly contracted by the rod or 100 feet as a unit; ditches are filled at a price per 100 feet.

The following suggested specifications will serve as a guide to the engineer and may be modified as required to meet special cases.

Engineer's Stakes.—The lines for the ditches are indicated on the field by stakes which have been set by the engineer, and the depths and grades given by him constitute a part of the specifications.

Digging the Ditches.—The digging of each ditch must begin at its outlet, or at its junction with another tile-drain, and proceed toward its upper end. The ditch must be dug along one side of the line of survey-stakes, and about ten inches distant from it, in a straight and neat manner, and the top soil thrown on one side of the ditch and the clay on the other. When a change in the direction of ditch is made, it must be done by means of a neat curve, but in all cases the ditch must be kept near enough to the stakes so that they can be used in grading the bottom. In taking out the last draft, the blade of the spade must not go deeper than the proposed grade-line or bed upon which the tiles are to rest.

Grading the Bottom.—The ditch must be dug to the

depth indicated by the figures given with the survey, which depth is to be measured from the grade-stakes which are set for that purpose, and graded evenly on the bottom by means of the line and gage method, target, or any other equally accurate device for obtaining an even and true bottom upon which to lay the tile. The bottom must be dressed with the tile-hoe, or, in case of large tiles, with the shovel, in such a way that a groove will be made to receive the tile, so that when laid in it they will remain securely in place.

Laying the Tile.—The laying of the tile must begin at the lower end and proceed up-stream. The tile must be laid as closely as practicable, and in lines free from irregular crooks, the pieces being turned about until the upper edges close, unless there is sand or fine silt which is likely to run into the tile, in which case the lower edges must be laid close, and the upper side covered with clay or other suitable material. When, in making turns, or by reason of irregular-shaped tile, a crack of one-fourth inch or more is necessarily left, it must be securely covered with broken pieces of tile. Junctions with branch lines must be carefully and securely made.

Blinding the Tile.—After the tile have been laid and inspected by the person in charge of the work, they must be covered with clay to a depth of six inches, unless, in the judgment of the engineer, the tile are sufficiently firm, so that complete filling of the ditch may be made directly upon the tile. In no case must the tile be covered with sand without other material being first used.

Risk during Construction.—The ditch contractor must assume all risks from storms and caving in of ditches, and when each drain is completed it must be free from sand and mud before it will be received and paid for

in full. In case it is found impracticable, by reason of bad weather or unlooked-for trouble in digging the ditch, or properly laying the tile, to complete the work at the time specified in the contract, the time may be extended as may be mutually agreed upon by employer and contractor. The contractor shall use all necessary precaution to secure his work from injury while he is constructing the drain.

Tile to be Used.—Tile will be delivered on the ground convenient for the use of the contractor. No tile must be laid which are broken, or soft, or so badly out of shape that they cannot be well laid and make a good and satisfactory drain.

Payments for Work.—Unless otherwise agreed, the contractor may at any time claim and receive from the employer seventy-five percent of the value of completed and accepted work at the price agreed upon in the contract. Twenty-five percent will be retained until the entire work contracted for is completed and accepted, at which time the whole amount due will be paid.

Prosecution of Work.—The work must be pushed as fast as will be consistent with economy and good workmanship, and must not be left by the contractor for the purpose of working upon other contracts, except by permission and consent of the employer. All survey-stakes shall be preserved and every means taken to do the work in a first-class manner.

Failure to Comply with Specifications.—In case the contractor shall fail to comply with the specifications, or refuse to correct faults in the work as soon as they are pointed out by the person in charge, the employer may declare the contract void, and the contractor, upon receiving seventy-five percent of the value of completed drains at the price agreed upon, shall release the work and the employer may let it to other parties.

Sub-letting Work.—The contractor shall not sublet any part of the work in such a way that he does not remain personally responsible, nor will any other party be recognized in the payment for work.

Plans and Tools.—The contractor shall furnish all tools which are necessary to be used in digging the ditches, grading the bottom, and laying the tile. In case it is necessary to use curbing for ditches, or outside material for covering the tile where sand or slush is encountered, the employer shall furnish the same upon the ground convenient for use. All plans and figures furnished by the engineer, together with the drawings and explanations, shall be considered a part of the specifications.

CHAPTER XII

FLOW IN OPEN CHANNELS

THERE are two classes of open channels required in draining land. These are ditches which are artificially constructed through swamps, level table lands without adequate natural drainage outlets, river bottom lands or salt marsh lands near the coast; and ditches which are made by enlarging, straightening, or otherwise improving natural streams or watercourses in such a manner as to reclaim and sufficiently protect adjoining land.

Velocity of Flow. As the velocity of the flow in such channels is an important factor in determining the size adequate for the work required of them, the engineer must be familiar with methods of computing it.

The velocity of water in open channels is retarded by its contact with the bottom and sides of the ditch, the resistance being greater or less according to the nature of the material through which the channel is cut, and the irregularities in the surface of that part of the ditch which the water touches.

The filaments of water from the bottom of the channel toward the surface, and from the sides toward the center of the channel form, respectively, vertical and horizontal curves, with the advanced portion of the curves in the center line of the stream.

If these curves were plotted, the resistance of the sides and of the bottom of the ditch would have the appearance of holding back the water so that no two filaments would have the same velocity. The greatest velocity of the stream is found in that part of the thread of the

current just underneath the surface, all other portions of the flow having a less velocity in proportion as they approach the bottom and sides of the channel. Velocity formulas give the mean velocity of flow for the channel, or, in other words, a single assumed uniform velocity which will give the same discharge as the several un-uniform ones which exist in the channel. In a trapezoidal channel the mean velocity is approximately eight-tenths of the surface velocity. This is found to be at a point in the center line of the stream about six-tenths of the distance from the bottom of the channel to the surface. The bottom velocity is from four-tenths to seven-tenths of the surface velocity, depending much upon the kind of material which forms the bottom and upon the size of the channel. Irregularities in bottom and sides of the channel, sharp bends and varying widths and depths modify the above general laws.

Formulas for Flow. There is greater difficulty in correctly expressing by formula the velocity of flow in open channels than in pipes, since the character of the wet perimeter is more variable and the resistances offered by the sides and bottom change with the rise and fall of the water in the channel. The velocity is due to the slope of the surface of the water which in channels with free flow is usually parallel with and due to the grade of the bottom. This surface slope, however, is sometimes increased by the addition of volumes of water from tributary streams along the line.

The Chezy formula, $v = c\sqrt{rs}$, (4) is the general expression for velocity in open channels now recognized by hydraulicians, where

c = a variable coefficient,

$$r = \text{hydraulic radius} = \frac{a}{p} = \frac{\text{area}}{\text{wet perimeter}},$$

$$s = \text{slope} = \frac{h}{l} = \text{fall of water surface per unit of length.}$$

Values for c may be substituted which will give corresponding corrections for differences in velocity due to roughness of the channel.

In **Kutter's formula** the method of determining c is substituted for c in the Chezy formula, thus:

$$v = \left\{ \frac{\frac{1.811}{n} + 41.6 + \frac{.00281}{s}}{1 + \left\{ 41.6 + \frac{.00281}{s} \right\} \frac{n}{\sqrt{r}}} \right\} \sqrt{rs} \quad . \quad . \quad (12)$$

in which n = coefficient of roughness. Its value must be assumed and substituted in the equation. The portion of the formula inclosed in large braces gives the value of c in the Chezy formula.

Value of n. No little uncertainty attends the selection of the correct value of n for open channels, because of their variable character, so that at the best some margin for error should be allowed in the results. The factor n while called the coefficient of roughness of the bottom and sides of the channel, is applied in practice to obstructions of all kinds which retard the flow, and represents the correction necessitated by the fact that the velocity is not strictly proportionate to $\sqrt{rs}$. Its value for open channels ranges between .02 and .05. Careful measurements have been made under the direction of Drainage Investigations of the U. S. Dept. of Agriculture to determine the value of this factor for drainage ditches in alluvial and clay lands. Its value for ditches 20 feet to 100 feet wide and 6 feet to 12 feet deep in fairly good condition is .028 to .03 and .035 for ditches in bad condition. Where ditches are in exceptionally good condition, such as clean-cut clays or gravel, .0225 to .025 may be used.

The following values of n are given in the hydraulic and excavation tables prepared by the U. S. Reclama-

tion service as approximately correct for the channels described.

.020, **Channels of fine gravel; canals in earth in good condition, lined with well-packed gravel, partly covered with sediment, and free from vegetation.**

.0225, **Channels in earth in fair condition, lined with sediment and occasional patches of algæ, or composed of loose gravel without vegetation.**

.025, **Canals and rivers of fairly uniform cross-section, and slope in average condition.**

.030, **Canals and rivers in poor condition with bed and banks partially covered with débris.**

.035, **Canals and rivers in bad condition, channel strewn with stones and about one-third filled with vegetation.**

.040, **Canals half-full of vegetation and with rough banks.**

On account of the tedious computations required in solving the equation for the value of c, short methods by means of tables or diagrams are commonly employed by engineers in finding the value of this coefficient. It is particularly desirable that necessary computation be as simple as possible consistent with reasonably accurate results. In order to facilitate the use of this formula, Table XI, giving the value of c for a wide range of drainage conditions in level areas, is inserted.

To use the table, find r and the slope of the proposed ditch, then in the table which gives the slope nearest that of the ditch under consideration find the corresponding value of r; opposite this in the column headed by the values of n will be found the value of c, which is to be substituted in the formula. In case corresponding values of r and s are not found in the table the value of c can be interpolated with sufficient accuracy.

TABLE XI *

Values of Coefficient c for Use in Kutter's Formula

	r Ft.	n = Coefficient of Roughness					
		.017	.020	.025	.030	.035	.040
		c	c	c	c	c	c
s = 1 in 20,000 = .264 ft. per mile	1	77	64	49	40	34	29
	2	94	79	62	51	44	38
	3	104	88	71	59	50	44
	4	111	95	77	64	56	49
	6	122	105	85	72	63	56
	8	129	111	91	78	68	61
	10	134	116	96	82	72	64
	16	144	126	106	91	81	73
	20	149	131	110	96	85	77
s = 1 in 10,000 = .528 ft. per mile	1	81	67	52	42	35	31
	2	96	81	64	53	45	39
	3	104	89	71	59	51	45
	4	111	94	76	64	55	49
	6	119	102	84	71	61	54
	8	124	107	88	75	66	59
	10	128	111	92	78	69	62
	15	135	118	98	85	75	68
	20	139	122	102	89	79	71
s = 1 in 5,000 = 1.056 ft. per mile	1	83	69	54	44	37	32
	2	97	82	64	54	45	40
	3	105	89	72	59	51	45
	4	111	94	76	63	55	48
	6	117	100	82	69	60	53
	8	122	105	87	73	64	57
	10	125	108	89	76	67	60
	15	131	113	95	82	72	65
	20	134	117	98	85	76	68
s = 1 in 2,500 = 2.112 ft. per mile	1	85	70	55	45	37	32
	2	98	83	65	54	45	40
	3	105	89	71	59	51	45
	4	110	94	76	63	55	48
	6	116	99	81	69	60	53
	10	123	107	88	75	66	59
	20	131	115	96	83	73	66

* From Trautwine's Engineers' Pocket-Book.

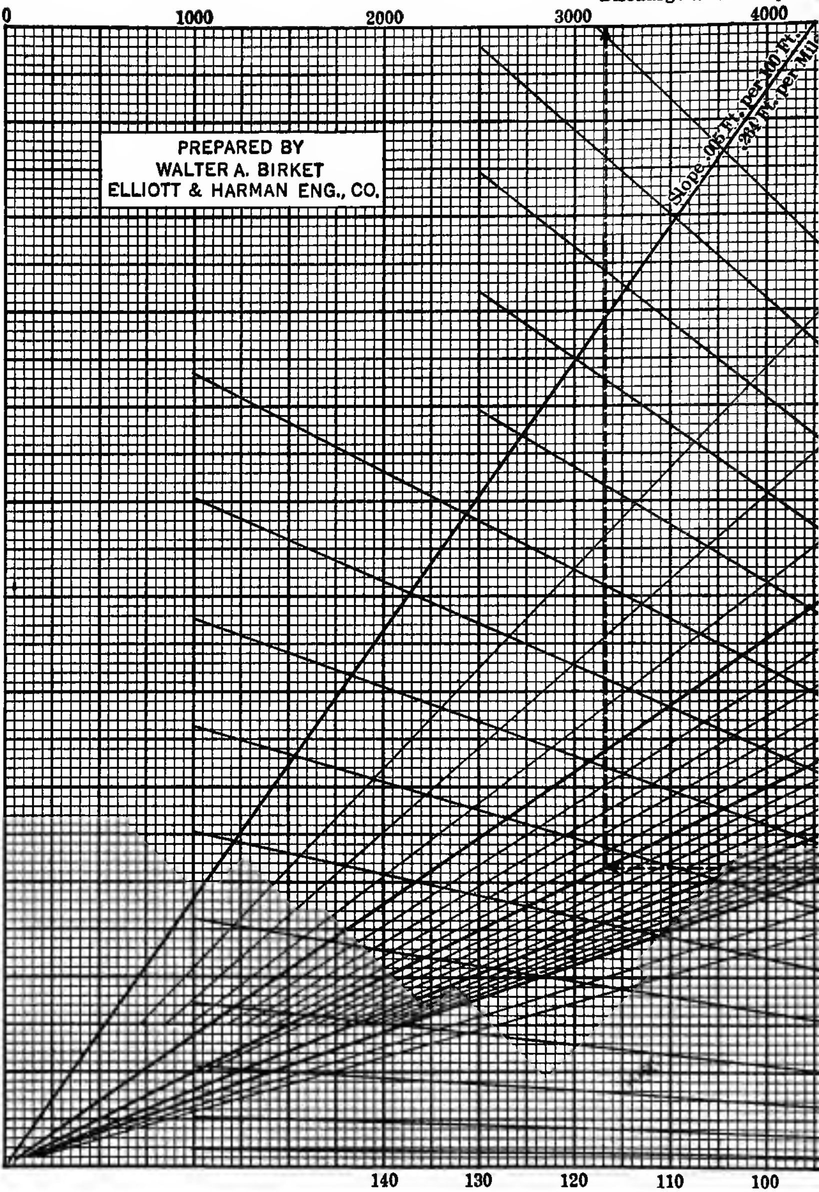
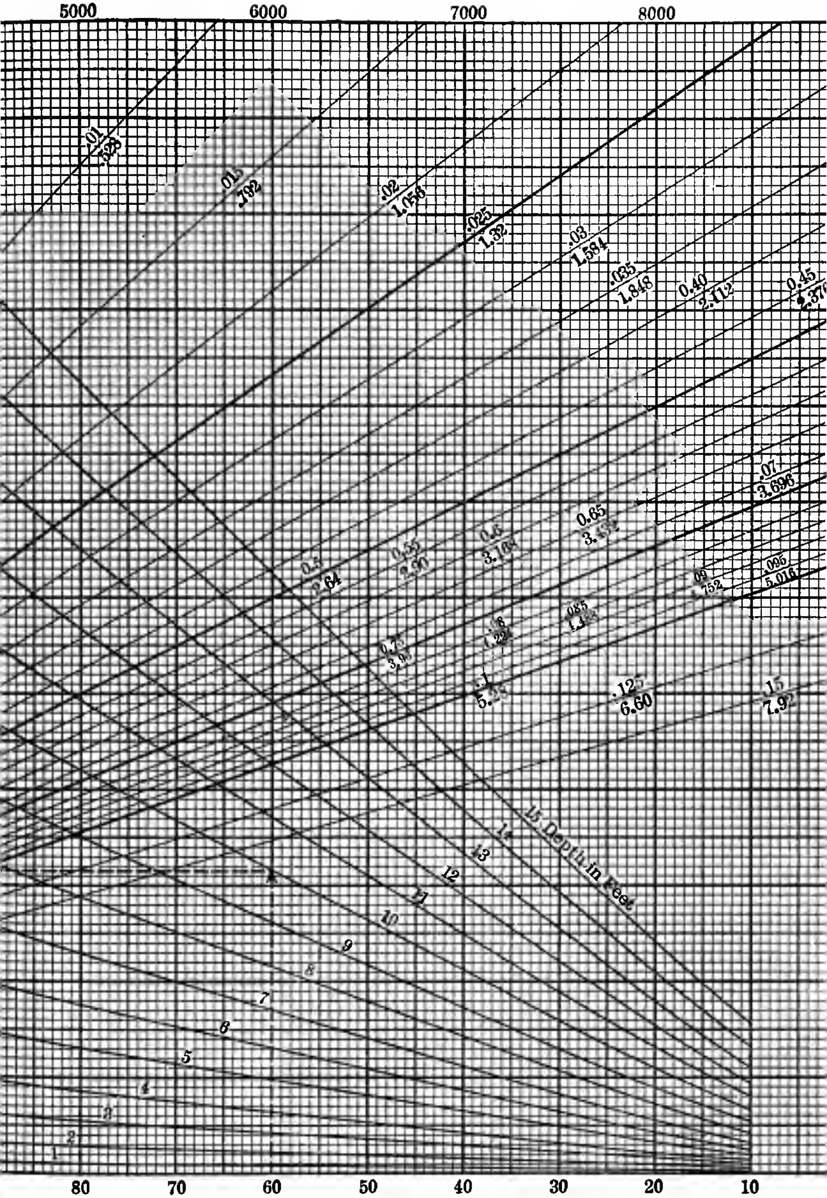


FIG. 35.—DIAGRAM FOR DETERM

Kutt... Formula $n = .080$



...tom width of Ditch, in feet, Side Slopes 1:1

THE DISCHARGE OF OPEN DITCHES.

TABLE XI.—Continued.

	r Ft.	n = Coefficient of Roughness					
		.017	.020	.025	.030	.035	.040
s = 1 in 1,000 = 5.28 ft. per mile	1	86	71	56	45	38	33
	2	98	83	66	54	46	40
	3	105	89	71	59	51	45
	4	110	93	75	63	54	48
	6	116	99	81	68	59	52
	10	122	105	87	74	65	58
	20	129	113	94	81	72	65
s = 1 in 100 = 52.8 ft. per mile	1	87	72	56	45	38	33
	2	99	83	66	55	46	40
	3	105	89	71	59	51	45
	4	109	93	76	63	55	48
	6	115	99	81	68	59	52
	10	121	105	86	74	65	58
	20	128	112	93	80	71	64

Kutter's formula, while more elastic and better adapted to all classes of hydraulic problems than the more simple expressions which have a fixed coefficient of flow, **c**, depends largely for the accuracy of its results upon the values which may be given to the coefficient of roughness, **n**. That factor is more or less indeterminate for ditches, so, as before remarked, some margin should be allowed for error. It is the view of the author that in applying the coefficient of drainage a liberal margin between the computed capacity of a ditch and that which it may be called upon to carry should be allowed.

Kutter's Formula—Diagram for Reading Discharge of Ditches Direct. Fig. 35 is a diagram prepared for reading without computations the discharge of ditches with side slopes of 1 to 1 when bottom width, depth and gradient are known. The quantities are computed with n = .030, which has been found the general value which should be used for ditches in their average

condition. The diagram may be used as a general guide in designing the larger type of drainage canals.

How to Use the Diagram. Find the bottom width of the ditch at the bottom of the diagram, interpolating by scale between numbers; pass upward to the diagonal line which indicates the depth of the ditch; from this point of intersection, pass to the left until the diagonal line indicating the gradient or slope of the surface of the water in the ditch is intersected; from that point, pass upward to the top and read the discharge in cubic feet per second.

Should the capacity of ditches of smaller dimensions or with other values of **n** be desired, the necessary computations may be made with the assistance of **Table XI** for obtaining the values of **c.** It should be noted that in all cases the slope that the surface of the water will take when the ditch is in operation is the slope that should be used in the formula and in the diagram.

Elliott's Formula. A more simple expression now known as Elliott's formula is one formerly used by English engineers, but modified by the author for use in the design of American drainage ditches. For ditches of ordinary size it gives about the same results as Kutter's with $n = .0225$. That coefficient has been found applicable to ditches whose perimeter is fairly clear of vegetation and other obstructions. In the design of ditches the author considers it good practice to use a medium drainage coefficient, and design the maximum flow of the ditches to be .8 of their depth at their shallow section. This provides a factor to meet heavy storms and failure of the formula to represent the conditions of the ditch as they may affect the velocity. The simplicity and tested value of the formula when used as directed leads the author to retain it and recommend its use.

ELLIOTT'S FORMULA

$$v = \sqrt{\frac{a}{p} \times 1.5\,h} \quad \dots \dots \dots \dots \quad (13)$$

$$Q = a\,v \quad \dots \dots \dots \dots \quad (5)$$

in which

v = mean velocity in feet per second
a = area of waterway in square feet
p = wet perimeter = length of bounding line of that part of the channel under water
h = fall in feet per mile
Q = discharge in cubic feet per second

The number of acres which will be drained by a ditch is found by dividing the discharge in cubic feet per second by the runoff in cubic feet per second per acre. By formula the expression is,

$$A = \frac{Q}{C} \quad \dots \dots \dots \dots \quad (11)$$

in which

A = number of acres
C = quantity taken from Table III

If the area in square miles is required, divide Q by the runoff per square mile taken from the same table.

Example:

The bottom width of a ditch is 20 feet, general depth 8 feet, side slopes 1:1, and grade 3 feet per mile. How many acres will be drained by it, using the ¼-inch drainage coefficient?

$$.8 \text{ depth} = 6.4$$
$$a = 170.9$$
$$p = 38 \qquad v = \sqrt{4.5 \times 4.5} = 4.5$$
$$\frac{a}{p} = 4.5$$
$$Q = 170.9 \times 4.5 = 769$$
$$A = \frac{769}{.0105} = 7324$$

The margin to be allowed between the surface of the water at maximum flow and the surface of the ground is subject to topographical conditions. With fairly uniform ground surface throughout the length, one foot margin will ordinarily be sufficient. It should be observed, however, that the depth of flow should be controlled by the depth of ditch which can be obtained through the low land, irrespective of depths which may be safely permitted in other sections of the ditch.

Relation of Depth to Mean Velocity. The effect of depth upon velocity in channels of the same width should be considered in the design of ditches, especially those having a light grade. Table XII shows these relations in a general way. Economy of construction and of subsequent maintenance as well as capacity are affected by these relations.

TABLE XII

Mean Velocity of Water at Different Depths in Rectangular Ditch, 10 feet wide, Grade 3 feet per mile

Depth in Ft.	Mean Vel. Ft. per Sec.
0.5	1.4
1.5	2.3
2.0	2.6
2.5	2.8
3.0	2.9
4.0	3.2
5.0	3.4
6.0	3.6
8.0	3.8

It is seen here that the mean velocity in a channel of the above width, with water 8 feet deep, is 45% greater than when the water is only 2 feet deep.

TABLE XIII

Relation of Width and Depth of Channel to Mean and Surface Velocity in Rectangular Channels

b = width, d = depth, v = mean velocity, V = surface velocity.

When	b = 2d	then	v = .920 V
"	b = 3d	"	v = .910 V
"	b = 4d	"	v = .896 V
"	b = 5d	"	v = .882 V
"	b = 6d	"	v = .864 V
"	b = 7d	"	v = .847 V
"	b = 8d	"	v = .826 V
"	b = 9d	"	v = .805 V
"	b = 10d	"	v = .780 V

The mean velocity and discharge is greatest in proportion to the excavation when the width is twice the depth, and when the section of the ditch is a semicircle.

CHAPTER XIII

THE RUNOFF FROM LARGE AREAS

THE relation of runoff to rainfall is an interesting as well as an important problem to the engineer. The value of water to the agriculturist demands that it be controlled, directed, and conserved in the most skilful and intelligent manner possible. A plentiful amount of the rainfall, which is unevenly distributed both in point of time and volume, must be stored in the soil for the nourishment of plants and supply of springs, yet a certain part must be promptly removed from the land by drainage, or injury will result in many ways. Rain disappears either as evaporation or runoff. The former term, as used in drainage discussions in distinction from runoff, refers not only to the water taken up by the atmosphere in the form of vapor, but is made to include that drawn from the soil by plants in their growth, and also that which passing into the lower strata of the ground remains as bottom-water. The term runoff is applied to free water which passes from the land in various ways into streams.

Evaporation. The rainfall can be accurately measured by means of the rain-gage, and the runoff can be determined by continuous gagings of the streams which receive the drainage from a given area. The difference between the two amounts is evaporation as here used, and while the greater of the two, it can be known only after the amount of runoff has been ascertained.

Precipitation occurs at intervals and in irregular quantities, but runoff is nearly continuous, and evapora-

tion entirely so. The latter goes on after drainage in any appreciable amount has for a time ceased, each growing plant drawing its water from the supply stored in the soil from rains occurring, perhaps, months before, but which has not been removed by drainage. Owing to this characteristic of soils, it is frequently shown by refined methods of measurements that for a short period evaporation is much greater than the rainfall for the same time. As a rule, it is least active when the demand for the drainage of land is greatest, because the humid state of the atmosphere during times of continuous precipitation checks the passage of vapor from the surface, and also because plants require less water from the soil at such times, owing to the supply of moisture which envelops their foliage. Though a most important agent in removing rainfall from the land, evaporation is so illusive when we attempt to assign to it a definite office in its relation to drainage that we are compelled to ignore it, and base our computations and conclusions regarding the amount of water that should be removed by drains upon measurements of actual runoff from different kinds of lands under varied climatic conditions.

Relation of Soil to Runoff. The condition of the land with reference to its ability to absorb and retain water is a much more certain and tangible element. This property permits the rapid reception and ample storage of rain so that in many instances a large precipitation will be followed by little runoff until the soil becomes filled, when a large percent will, for a time, be delivered to the drains. Where lands have soils of dense clay or where the surface is rolling and comparatively non-absorptive, the runoff is more rapid than it should be. In such cases efforts should be directed toward checking the surface flow and treating the land

so that more water will be absorbed and stored for the use of vegetation.

The distributing effect of soil, the relief afforded by surface depressions, and the time which is required for rain to reach the drains makes it possible to accomplish drainage with ditches which carry a small proportion

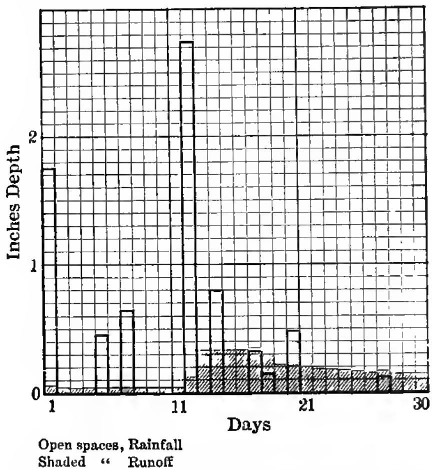


FIG. 36.—RAINFALL AND RUNOFF NEW ORLEANS TRACT, DECEMBER, 1909.

of the rainfall. To the novice it seems hardly possible that drains with a capacity for removing one-half inch of water in 24 hours would furnish sufficient drainage for a tract when the precipitation upon it is two or more inches in the same time. We may state all of these truths in a general way, but cannot reduce them to figures which can be applied to the design of drainage works until we have some experiments relating to actual requirements under given conditions, upon which to base computations of the amount of runoff which should be provided for.

Runoff Investigations. A study of the drainage needs of tracts as ascertained by careful examinations and measurements will enable the engineer to handle this phase of the subject successfully. Such a study should take into consideration all of the conditions which modify runoff in the particular locality which is examined. The following reports of investigations along this line and deductions from the results will assist the

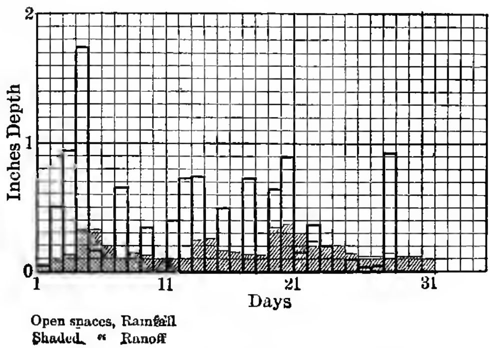


FIG. 37.—RAINFALL AND RUNOFF NEW ORLEANS TRACT, JULY, 1910.

engineer in determining the relation of drainage to rainfall from the standpoint of benefits to land for agriculture.

The New Orleans Land Company's Tract near New Orleans, La.,* is a level tract of 1,085 acres, originally covered with cypress timber which is now largely cleared off. Its length is about double the width, and it is enclosed by levees and drained by two large canals which discharge at one corner over a measuring weir. Little of the land is cultivated, but mainly covered, instead,

* Investigations by W. B. Gregory, A. M. Shaw, and C. W. Okey of Drainage Investigations, U. S. Department of Agriculture.

with a rank growth of weeds. Lateral ditches, which later will be required for complete drainage, have been constructed in but few instances. The runoff was measured continuously, with two exceptions, from

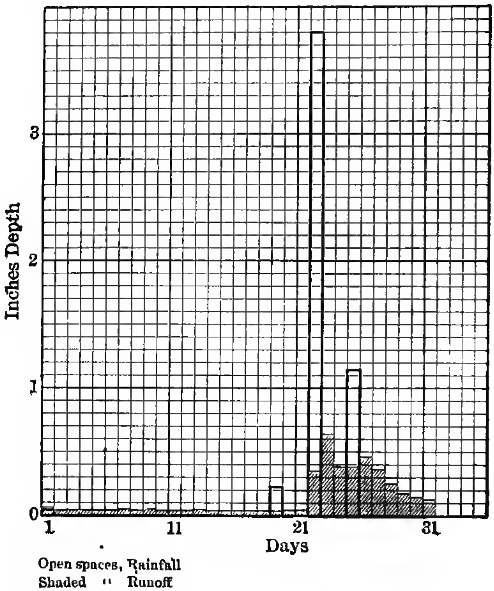


FIG. 38.—RAINFALL AND RUNOFF NEW ORLEANS TRACT, MARCH, 1911.

June, 1909, to March, 1911, by means of the weir and the rainfall was measured by a standard rain-gage.

The records of three detached months have been selected to represent the relation of the drainage from that tract to the rainfall. The tabulated record which follows (**Record No. 7**) is also graphically arranged in **Figs. 36, 37** and **38**, to show this relation at a glance.

These months are fairly representative as to amounts

RECORD NO. 7

New Orleans Land Company's Tract, Area 1085 Acres

Runoff given in inches of depth in 24 hours

Day	Dec., 1909		July, 1910		March, 1911	
	Runoff	Rain	Runoff	Rain	Runoff	Rain
	Ins.	Ins.	Ins.	Ins	Ins.	Ins.
1	.018	1.74	.047	.05	.035	.01
2	.031	....	.082	.49	.034	....
3	.051	....	.136	.95	.032	....
4	.051	....	.335	1.74	.032	....
5	.055	.46	.309	.14	.033	....
6	.055	....	.220	....	.033	....
7	.055	.65	.178	.66	.033	....
8	.055	....	.150	....	.033	....
9	.065	....	.122	.35	.032	....
10	.059	....	.122	....	.025	....
11	.059	....	.116	.40	.019	....
12	.120	2.74	.129	.73	.016	....
13	.337	....	.237	.71	.016	....
14	.331	.80	.247	....	.015	....
15	.320	....	.179	.51	.014	....
16	.327	....	.145	....	.012	....
17	.313	.33	.122	.73	.012	....
18	.259	.12	.114	.55	.011	....
19	.209	....	.342	.65	.014	.23
20	.206	.48	.388	.92	.016	....
21	.202	....	.291	.17	.015	....
22	.198	....	.232	.37	.366	3.80
23	.194	....	.194	.20	.623	....
24	.191	....	.157		.374	....
25	.187	....	.136	.10	.374	1.15
26	.184	....	.120	.04	.450	....
27	.180	.11	.124	.04	.380	....
28	.177	....	.117	.91	.244	....
29	.172	....	.100	....	.174	....
30	.168	....	.090	....	.145	....
31	.125	....	.072	....	.114	....

Deductions and Comments	Dec., 1909	July, 1910	March, 1911
Total rainfall............	7.43 in.	11.4 in.	5.18 in.
Total runoff............	4.97 "	5.36 "	3.72 "
Max. runoff in 24 hrs......	.337 "	.387 "	.62 "
No. days that runoff was .3 inch or more for 24 hrs...	5	4	6
Ratio of runoff to rainfall...	66.89	47.02	71.81

RECORD NO. 8

Monthly Rainfall, United States Weather Bureau Station, New Orleans

Year	Monthly and Annual Precipitation												
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1871..	6.75	1.59	4.47	2.29	5.08	8.61	4.34	7.21	6.59	9.09	7.14	1.46	64.62
1872..	5.10	4.77	9.18	5.01	3.14	5.34	6.43	3.75	2.10	3.18	7.43	5.25	60.68
1873..	5.06	1.93	5.10	1.74	18.68[a]	6.68	5.22	8.30	3.21	1.89	5.95	1.79	65.55
1874..	1.68	3.68	5.37	13.62	.22	9.62	12.93[a]	4.82	4.21	T.[b]	1.12	3.27	62.74
1875..	8.44	13.85[a]	10.84	8.05	2.53	4.92	6.57	8.61	7.89	2.09	6.79	5.15	85.73[a]
1876..	4.43	8.20	11.32	6.41	7.10	6.20	4.73	4.44	.26	.24	4.35	9.57	67.25
1877..	5.30	.98	4.94	4.79	1.48	2.75	6.41	2.54	13.21	9.15[a]	6.58	4.96	63.09
1878..	5.36	3.50	4.63	1.51	8.11	7.35	6.21	5.31	2.64	5.07	7.78[a]	8.69	66.16
1879..	2.34	2.13	1.36	9.17	4.63	2.96	7.04	10.44	3.15	1.36	3.79	2.90	51.27
1880..	1.02	4.62	6.66	6.88	6.55	6.43	11.22	4.60	7.48	1.88	6.04	6.45	69.83
1881..	11.15[a]	5.80	2.75	3.92	3.20	2.84	6.97	4.21	4.47	4.84	7.24	6.62	64.01
1882..	4.54	4.04	.92	4.83	6.83	2.71	6.84	9.47	1.59	2.16	1.98	4.27	50.18
1883..	10.63	1.59	5.01	14.20[a]	5.41	12.05[a]	3.33	4.12	.25[b]	3.43	6.36	3.47	69.85
1884..	4.35	3.16	8.24	6.48	4.33	8.60	4.12	.87[b]	3.12	5.60	3.13	8.01	60.01
1885..	9.70	2.39	6.99	3.67	5.77	3.30	6.15	4.25	13.55	.56	3.47	4.38	64.18
1886..	7.53	1.96	8.41	5.60	3.07	9.30	4.35	2.40	4.09	.22	5.33	2.57	54.83
1887..	4.26	5.58	3.37	1.87	3.99	11.33	7.85	7.42	6.51	4.71	.52	7.56	64.97
1888..	3.29	11.21	6.45	1.89	9.75	9.09	2.02[b]	22.74[a]	4.15	7.36	1.50	3.68	83.13
1889..	6.51	2.78	3.86	2.28	1.17	7.62	9.13	5.59	6.40	.26	2.18	.67[b]	48.45
1890..	.66[b]	2.27	1.45	3.46	5.32	7.71	6.59	3.62	2.85	5.24	.42	2.58	42.17

[a] Highest monthly or annual. [b] Lowest monthly or annual.

RECORD NO. 8—Continued

Year	Monthly and Annual Precipitation												
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1891..	3.75	7.42	2.67	.26[b]	.76	4.45	4.57	1.69	3.43	2.38	3.31	3.93	38.62
1892..	5.87	.04[b]	2.82	10.44	2.62	5.46	7.46	6.96	6.33	2.14	3.55	3.22	56.91
1893..	2.50	4.92	3.49	3.70	2.66	5.30	3.72	4.56	4.38	4.24	6.24	2.31	48.02
1894..	1.76	11.06	5.94	4.71	1.79	5.19	11.51	7.32	.92	.89	1.34	2.01	54.44
1895..	7.19	3.92	3.81	2.58	7.95	9.74	6.07	6.79	1.97	1.21	.69	4.52	56.44
1896..	2.33	2.78	5.29	4.84	2.80	8.23	2.92	3.31	5.26	5.33	2.82	3.77	49.68
1897..	1.92	4.82	4.82	5.75	.25	4.82	4.70	3.12	3.19	2.70	3.38	4.00	43.47
1898..	1.71	6.20	.80[b]	2.80	.02[b]	3.79	4.57	6.24	13.90[a]	1.77	5.17	2.03	49.00
1899..	2.44	2.93	2.71	1.56	.14	7.80	5.45	2.31	.35	.89	1.70	2.79	31.07[b]
1900..	3.69	5.46	4.00	10.69	2.91	5.10	6.06	4.19	3.76	3.55	1.29	5.61	56.33
1901..	4.24	5.78	4.26	7.79	1.08	4.46	10.71	5.80	3.30	2.67	2.78	4.87	57.73
1902..	.97	3.83	4.07	3.71	1.56	1.46	4.24	2.93	6.68	2.42	3.65	6.09	41.61
1903..	4.01	10.20	14.61[a]	.97	1.11	3.61	7.17	7.48	3.32	.81	.18[b]	3.71	57.18
1904..	3.58	1.52	4.12	1.94	4.31	5.59	8.49	5.83	2.84	1.20	1.90	2.37	43.69
1905..	6.31	5.32	7.80	5.89	4.23	7.55	5.93	3.95	11.09	5.95	3.62	14.43[a]	80.07
1906..	2.57	2.25	5.53	1.08	.70	4.39	7.32	4.88	7.40	1.08	1.03	3.36	41.59
1907..	2.14	4.47	2.30	13.18	14.74	.98[b]	4.47	5.28	5.31	1.61	4.96	6.88	66.32
1908..	4.50	4.14	3.28	1.34	4.77	2.39	11.03	5.65	10.70	.78	.69	1.79	51.06
Mean	4.46	4.56	5.10	5.02	4.23	5.94	6.39	5.61	5.05	2.89	3.62	4.50	57.42

[a] Highest monthly or annual. [b] Lowest monthly or annual.

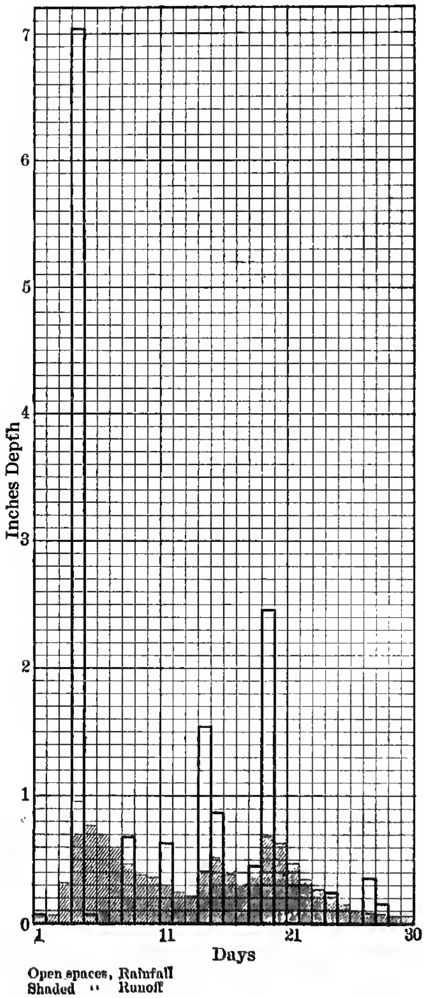


FIG. 39.—RAINFALL AND RUNOFF HOPSON BAYOU, APRIL, 1911.

of precipitation, but by reference to the rainfall record in that locality for 38 years past, it is apparent that greater monthly and annual precipitation must be provided for occasionally. The records of the tract referred to show that the demand for drainage may be greater per day during a month in which the total precipitation is small than when it is large. As shown in **Record No. 9**, the mean annual rainfall at New Orleans for the period 1871–1908 amounts to 57.42 inches, the minimum 31.07 inches, and maximum 85.73 inches.

Hopson Bayou Drainage District, Coahoma County, Miss., has an area of 15,000 acres and discharges its drainage through a free outlet ditch, 16 feet wide. The tract has about the same width as length, and besides the main canal has several lateral ditches. About one-half the area is in cultivation. There are swampy portions which have not been drained and which will retain considerable water until filled, after which the runoff from them is rapid. The soil is heavy buckshot. But little rain fell in March, but in April, 14.43 inches fell, as shown in the following record. The relation of the runoff to the rainfall is shown in **Record No. 9**, and represented graphically in **Fig. 39**.

The greatest runoff was .9 inch, which was for one day only. There were five days during the month when the runoff exceeded .6 inch. A comparison of the rainfall of this month with **Record No. 10** shows that the precipitation for the month greatly exceeded that of any other month in the 8 years. It is probable that a drainage coefficient of .75 inch is about correct for that area under the conditions which now exist.

The Willswood Plantation, St. Charles Parish, La. This tract consists of 2,400 acres of cultivated land, and is provided with a system of open ditches and pumps, which furnish good drainage. It is nearly rectangular

RECORD NO. 9

Daily Rainfall and Runoff in Hopson Bayou Drainage District, Coahoma County, Miss., for April, 1911. Area 15,000 Acres *

Date	Rainfall, Ins.	Drainage Coefficient, Ins.
April 1	....	.045
" 2	....	.039
" 3	....	.318
" 4	7.05	.952
" 5	.06	.767
" 6	....	.700
" 7	....	.593
" 8	.68	.472
" 9	....	.376
" 10	....	.332
" 11	.64	.304
" 12	....	.254
" 13	....	.210
" 14	1.52	.416
" 15	.86	.512
" 16	....	.402
" 17	....	.279
" 18	.44	.416
" 19	2.44	.682
" 20	....	.610
" 21	....	.488
" 22	....	.365
" 23	....	.279
" 24	.22	.197
" 25	....	.130
" 26	....	.086
" 27	.36	.085
" 28	.16	.077
" 29	....	.061
" 30	....	.053
Total	14.43	10.500

Runoff 72.7 per cent. of Rainfall.

* Measurements by C. W. Okey, Drainage Investigations, U. S. Dept. of Agriculture.

RECORD NO. 10

Monthly and Annual Rainfall at Clarksdale, Coahoma County, Miss.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1904	2.50	1.29	7.85	4.04	1.99	3.05	6.56	1.85	0.67	0.48	2.77	8.45	41.50
1905	6.91	2.65	7.54	6.86	9.60	6.15	2.48	2.01	4.26	5.09	3.20	5.86	62.60
1906	3.50	1.16	4.15	5.05	6.71	5.35	7.52	4.95	9.81	3.17	10.72	7.29	69.38
1907	1.69	3.11	5.70	5.15	11.26	2.19	1.72	3.00	2.08	1.96	3.98	3.91	45.75
1908	6.28	8.32	4.38	4.72	4.92	2.64	3.05	3.01	1.18	0.00	4.57	3.72	46.79
1909	2.17	6.48	4.68	4.56	9.60	2.77	1.33	3.65	2.47	0.72	2.66	8.35	49.44
1910	5.66	5.53	0.80	3.84	5.21	7.36	11.64	3.81	0.02	3.79	0.78	2.93	51.37
1911	2.05	5.16	2.89	14.43	0.28	......	......	......	......	......	......	......	......
Aver	3.84	4.21	4.75	6.08	6.18	4.21	4.90	3.18	2.93	2.17	4.08	5.77	52.40

in shape, the Mississippi River levee forming one side and the pumps being located on the opposite side midway between the corners. The surface-slope is unfavorable for draining by pumps because the section

RECORD NO. 11

Daily Rainfall and Corresponding Amount of Drainage Removed by Pumps from Willswood Plantation, St. Charles Parish, La., from June to October, 1909 *

Day	June		July		August		September		October	
	Rain-fall	Drain-age	Rain-fall	Drain-age	Rain-fall	Drain-age	Rain-fall	Drain-age	Rain-fall	Drain-age
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
1	0.15	......	0.12	......	0.56	......	......	......	......	......
2	4.10	0.88	.04	......	.48	0.20	......	......	......	......
3	1.00	1.42	.02	......	......	......	......	......	......	......
4	......	.76	......	......	......	......	......	......	......	......
5	......	.23	......	......	......	......	......	......	......	......
6	......	......	.03	......	......	......	......	......	......	......
7	......	......	......	......	.63	......	......	......	0.35	......
8	......	......	......	......	.07	......	0.53	......	......	......
9	......	.27	......	......	1.70	......	......	......	.10	......
10	......	......	.22	......	1.12	.60	......	......	.78	......
11	......	......	.05	......	......	.68	......	......	......	......
12	.25	......	.15	......	.83	.42	......	......	......	0.16
13	.66	......	......	......	.26	.30	1.40	......	......	......
14	.49	......	......	......	......	.26	......	0.15	......	......
15	......	......	.02	......	......	......	......	......	......	......
16	......	......	......	......	......	......	.05	......	......	......
17	......	......	.32	......	......	......	......	......	......	......
18	.20	......	.20	......	......	......	......	......	......	......
19	.93	......	......	......	......	......	......	......	2.04	......
20	1.22	.51	1.48	......	......	......	4.14	1.03	.96	.29
21	.43	.43	......	0.20	.06	.14	.30	.74	......	.20
22	.06	.47	......	......	......	......	......	.34	......	......
23	.40	......	......	......	1.11	......	......	......	......	......
24	.04	......	.02	......	.10	......	......	.18	......	......
25	......	......	......	......	......	.17	......	......	......	.19
26	......	.21	.50	......	.70	......	......	......	......	......
27	.32	......	.14	......	......	......	......	......	......	......
28	.17	......	2.24	.20	......	.20	......	......	......	......
29	......	......	......	.27	......	......	......	......	......	......
30	......	......	......	......	......	......	......	......	......	......
31	......	......	.09	......	......	......	......	......	......	......
Total	10.42	5.18	5.64	0.67	7.62	2.97	6.42	2.44	4.23	0.84

* From report of A. M. Shaw to Drainage Investigations, U. S. Dept. of Agriculture.

RECORD NO. 12

Percent of Drainage to Rainfall, Same Tract *

Month	Rainfall, Ins.	Drainage, Ins.	Drainage % of Rain
June	10.42	5.18	49.6
July	5.64	.67	11.9
August	7.62	2.97	39.0
September	6.42	2.44	38.0
October	4.23	.84	19.9

* From report of A. M. Shaw, Drainage Investigations, U. S. Dept. of Agriculture.

next to the river levee has considerable slope, causing the water to flow to the pumps too rapidly. This taxes the capacity of the pumps severely in order to prevent injury of the lower land by the overflow of the ditches. The soil is receptive in character and the fields are drained by small open ditches 100 feet apart.

Record No. 11 shows the daily rainfall and the amount of water in inches removed by the pumps each day from the entire tract, while **Record No. 12** gives the relation of these.

The data quoted show that at times when a 4-inch rain occurred the pumps removed in one instance 1.4 inch, and in another 1.03 inch in one day, but that ordinarily the maximum was .7 to .8 inch. Were the land level, so that the water would distribute itself evenly throughout the system, it is probable that .75 inch would be about the proper coefficient.

Boggy Bayou Tract, Desha Co., Ark. The surface of this 135,000 acre tract is nearly level and the soil heavy, underlaid with clay. The larger part is wooded and traversed by bayous and sloughs which bring the water into a small lake. A ditch was constructed from the lake four miles south to a point where there was a free discharge. The discharge of this ditch was measured

at the various heights of the water as read upon a gage, and a rating curve constructed. During April, 1911, the rainfall amounted to 13.72 inches, which is the largest

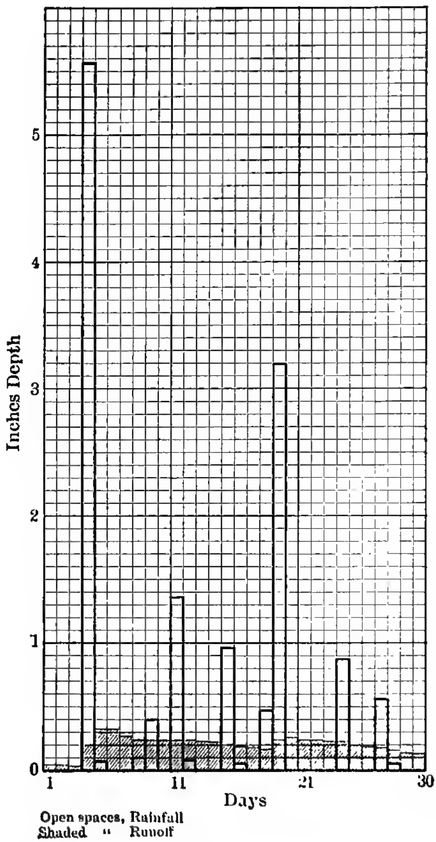


FIG. 40.—RAINFALL AND RUNOFF BOGGY BAYOU, APRIL, 1911.

precipitation recorded for any one month for the last 17 years. **Record No. 13** gives the rainfall as it occurred,

RECORD NO. 13

Boggy Bayou Tract, Desha Co., Ark. 135,000 Acres.
Rainfall and Runoff for April, 1911 *

Date	Rainfall, Ins.	Height of Gage, Ft.	Depth of Run-off, Ins.
1		131.6	.0379
2		130.9	.0291
3		130.3	.0220
4	5.60	137.9	.2070
5	.04	138.7	.320
6		138.7	.320
7		138.6	.282
8	.10	138.5	.264
9	.40	138.4	.247
10		138.3	.238
11	1.36	138.3	.238
12	.08	138.3	.238
13		138.2	.229
14		138.0	.213
15	.96	137.9	.207
16	.02	137.8	.201
17		137.6	.192
18	.48	137.5	.187
19	3.20	138.3	.238
20		138.4	.247
21		138.4	.247
22		138.3	.238
23		138.1	.220
24	.88	138.1	.220
25		137.9	.207
26		137.7	.196
27	.56	137.4	.183
28	.04	137.0	.166
29		136.4	.145
30		135.5	.119
Total	13.72		6.098

* From report of D. L. Yarnell, Drainage Investigations, U. S. Dept. Agriculture.

the height of the water on the gage, and the corresponding daily runoff for the entire area. It should be understood that the ditch merely takes the overflow from 135,000 acres which has but little natural drainage. The rains of April 4th and 5th caused a rise of 8.4 feet in the water of the ditch, due largely to drainage which came to it from near-by territory, and taxed the ditch to its full capacity. From that time on, large volumes flowed away through the flat country into another bayou so that the record shows a maximum runoff of only .32 inch per day. The actual total runoff was estimated at not less than .6 inch. The record shows conditions of flow from a large level area which has but few drainage channels and for which the outlet is not sufficient. It is represented graphically in **Fig. 40.**

Vermillion River Drainage District, Livingston Co., Illinois.* This is a level table-land of 128,000 acres, lying at the head of Vermillion River, and forming the upper part of its watershed. The entire drainage is accomplished by a system of artificial ditches from 8 ft. to 70 ft. wide, the farms for which they serve as outlets being drained by tile. The area represents a well-drained level portion of the State, so that the data relating to the operation and effect of outlet-ditches may be taken as a guide for draining that class of lands. The rainfall and runoff for this district is given in **Record No. 14,** and represented graphically in **Fig. 41.**

The rainfall for May was greater than that of any one month during the ten previous years, with the exception of June, 1902, so that the amount recorded may be regarded as the maximum discharge which will be required of the outlet in that part of the State.

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* From report of runoff from drained areas in Illinois and Iowa, by L. L. Hidinger, Drainage Investigations, U. S. Dept. of Agriculture.

RECORD NO. 14

Vermillion River Drainage District, 128,000 Acres. Rainfall and Runoff in May, 1908

Date	Rainfall, Ins.	Gage Height, Ft.	Runoff Depth, Ins.
1	.05	7.05	.082
2	.03	6.02	.064
3	....	6.00	.060
4	1.26	6.15	.063
5	.50	8.03	.132
6	.09	10.05	.224
7	.60	10.70	.276
8	.10	11.45	.336
9	.06	12.00	.380
10	....	11.05	.304
11	.55	9.70	.206
12	....	9.70	.206
13	1.61	10.70	.273
14	.40	11.65	.352
15	....	11.90	.372
16	....	10.80	.282
17	....	9.90	.222
18	.54	9.75	.210
19	.87	10.45	.256
20	....	10.95	.296
21	....	10.40	.252
22	.46	9.65	.202
23	....	8.50	.140
24	.40	6.05	.061
25	....	4.90	.038
26	.15	4.15	.023
27	....	4.40	.028
28	.40	5.15	.043
29	.63	5.70	.054
30	....	6.20	.064
31	.02	6.20	.064
Total	8.72		5.562

For annual rainfall in Illinois see Record No. 3.

A number of districts in the drained portion of the State have been examined in a similar manner, and from the results which are obtained a curve has been constructed to represent the relation and amount of run-off to districts of different areas in that section. (Fig. 43.) It should be noted that the ditches in the smaller areas do not, in many instances, run full, as it is desirable to keep the flood-plane of the ditches considerably

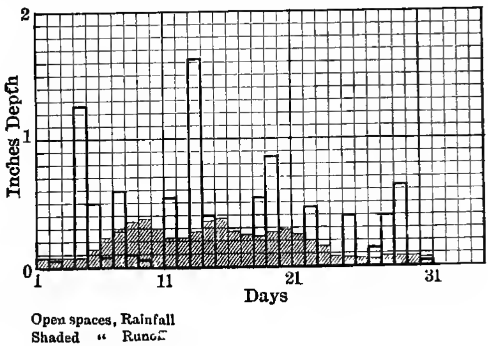

Fig. 41.—Rainfall and Runoff Vermillion River District, May, 1908.

below the surface of the land so that the tile-drains which discharge into them may operate without serious interruption. For this reason the trend of good practice is to make the ditches of such capacity that the level of ordinary flood-flow will not reach the top of the ditch.

Relation of Drainage Coefficient to Area. In general, the drainage coefficient is largest for small areas and diminishes as the areas increase, in a ratio dependent upon the topography of the watershed and the amount and duration of precipitation on its several parts.

In the reclamation of bottom-lands adjacent to

streams which are subject to overflow, the volume of water must be estimated by gagings or by comparing them with other streams whose watersheds and discharges are approximately known. The runoff from hilly sections is so far different from the more level sections that each valley must become the subject of a special examination.

Record No. 15, showing the flood runoff from some representative streams in the Middle West and the South, indicates the general range of maximum discharge from the streams named. The topography of the watershed of each stream and also the season of the year when the measurement occurred should be noted.

How to Select the Drainage Coefficient. Summing up the matter contained in the foregoing discussion, the engineer should take under consideration the following factors and conditions when selecting the drainage coefficient for a new district which is to be drained.

First, **rainfall and temperature.** Localities which have a large annual rainfall usually have a correspondingly large precipitation during one or two months, and those months have large 24- and 48-hour storm periods. It is during such periods that the greatest capacity for ditches is required. Lands in warm climates require as large drainage channels in proportion to rainfall as those in cold climates where the surface and soil are similar. While the total annual runoff in the former is not so great as in the latter, because of increased evaporation during part of the year, the requirements of ditches in order to meet the demands of storm periods are not essentially different.

Second, **topography of the area.** Level areas require smaller coefficients than those which are undulating and hilly, because the land absorbs more water and

RECORD NO. 15

Maximum or Flood Discharge of Streams Reported in Water Supply Papers Published by the U. S. Geological Survey, and Corresponding Rainfall from Weather Bureau Records *

State	River	Gage Station	Character of Water-shed		Date of Flood	Drainage Area Sq. Miles	Discharge Sec. Ft.	Runoff Inches Depth per 24 Hours	Rainfall	
			Upper End	Lower End					Monthly Ins.	Excess Over Normal Ins.
Iowa	Wapsipinicon	Stone City	Flat	Flat	July 13, '03	1,308	10,471	.30	6.78	+2.83
"	Cedar	Cedar Rapids	"	Foot-hills	May 31, "	6,317	52,450	.31	6.11	+1.59
"	Iowa	Iowa City	"	"	June 3, "	3,317	19,450	.22	6.90	+2.54
"	Des Moines	Koosauqua	"	Flat	" 1, "	14,291	97,140	.25	4.84	+0.28
"	" "	Des Moines	"	"	" 3, "	6,462	22,101	.13	10.64	+5.94
Neb.	Niobrara	Valentine	Mts	Hilly	July 18, '03	6,070	7,000	.04	3.95	+1.45
"	Elkhorn	Arlington	Flat	Flat	Aug. 29, "	5,980	8,670	.05	11.47	+6.94
"	"	Norfolk	"	"	May 31, "	2,474	8,000	.12	6.81	+2.94
"	Loup	Columbus	"	"	Aug. 1, "	13,542	20,000	.05	6.28	+3.05
"	North Loup	St. Paul	"	"	July 29, "	4,024	4,500	.04	6.85	+2.43
"	Middle Loup	"	"	"	May 30, "	6,849	12,400	.07	7.44	+3.85
Kans.	Verdigris	Liberty	Foot-hills	Flat	May 23, '03	3,067	41,450	.50	9.73	+4.95
"	Arkansas	Syracuse	"	"	June 11, "	24,960	28,300	.04	3.60	+1.49
"	Kansas	Lecompton	Mts	Foot-hills	May 31, '03	58,550	221,000	.14	7.06	+2.46
"	Blue	Manhattan	Foot-hills	"	" 31, "	9,490	68,770	.27	9.60	+5.28
"	Republican	Junction	Mts	"	" 30, "	25,837	47,520	.07	13.36	

* Compiled by H. A. Kipp, Drainage Investigations, U. S. Dept. Agriculture.

RECORD NO. 15—Continued

State	River	Gage Station	Character of Water-shed: Upper End	Character of Water-shed: Lower End	Date of Flood	Drainage Area Sq. Mile	Discharge Sec. Ft.	Runoff Inches Depth per 24 Hours	Rainfall: Monthly Ins.	Rainfall: Excess Over Normal Ins.
Kans.	Solomon	Niles	Mts.	Foot-hills.	June 3, '03	6,817	10,602	.06	9.30	+6.07
"	Neosho	Iola	Foot-hills.	Flat	" 3, "	3,670	39,120	.40	8.96	+4.69
Mo.	Gasconade	Arlington	Flat	Flat	May 31, '03	2,725	15,820	.22	8.47	+2.31
Ill.	Rock	Rockton	Foot-hills.	Foot-hills.	July 23, '03	6,150	11,990	.07	5.25	+1.55
"	Illinois	Peoria	Flat	"	Apr. 18, "	13,249	44,090	.12	5.15	
"	"	Lasalle	"	"	" 8, "	11,714	42,290	.13	4.81	
"	"	Ottawa	"	"	" 10, "	10,094	46,900	.17	5.08	+2.30
"	"	Minooka	"	Flat	" 8, "	6,476	36,810	.21	3.62	+1.71
"	"	"	"	"	Mar. 26, '04	6,480	64,810	.37	4.97	+1.79
"	Des Plaines	Channahon	"	"	Apr. 2, "	1,170	10,790	.34	4.97	+1.79
Ind.	Wabash	Logansport	Flat	Flat	Mar. 27, '04	3,163	56,140	.66	8.28	+5.26
"	Tippecanoe	Delphi	"	"	" 1, "	1,890	17,730	.35	7.46	+4.43
"	White (W. Br.)	Indianapolis	Foot-hills.	"	" 27, "	1,520	17,030	.42	10.95	+7.36
"	" (E. Br.)	Shoals	"	"	" 29, "	4,900	79,430	.60	10.50	+6.74
"	Wabash	Logansport	Flat	"	May 12, '05	3,163	33,750	.40	5.40	+1.21
"	White (E. Br.)	Shoals	"	Foot-hills.	Aug. 6, '03	4,900	6,780	.05	2.18	−1.37
"	Tippecanoe	Delphi	"	Flat	Apr. 14, "	1,890	12,060	.24	4.94	+1.90
"	Wabash	Logansport	"	"	July 2, "	3,163	32,885	.38	5.29	+2.77
Ohio	Licking	PleasantValley	Mts	Mts	Mar. 1, '03	696	8,210	.44	5.27	+1.90

RECORD NO. 15—Continued

State	River	Gage Station	Character of Water-shed		Date of Flood	Drainage Area Sq. Mile	Discharge Sec. Ft.	Runoff Inches Depth per 24 Hours	Rainfall	
			Upper End	Lower End					Monthly Ins.	Excess Over Normal Ins.
Wis.	Chippewa	Eau Claire	Flat	Foot-hills.	Sept. 16, '03	6,740	51,810	.28	9.12	+5.63
"	Flambeau	Ladysmith	"	"	May 31, "	2,120	12,750	.22	8.88	+5.18
"	Wisconsin	Necedah	"	"	Sept. 20, "	5,800	34,840	.22	4.47	
"	"	Merrill	"	Flat	May 27, '04	2,630	18,140	.26	5.50	+1.55
Va.	Staunton	Randolph	Mts	Foot-hills.	Mar. 24, '03	3,076	29,850	.36	7.14	
"	Roanoke	Roanoke	"	Mts	Aug. 11, '04	388	2,390	.23	2.62	
N. C.	Cape Fear	Fayetteville	Flat	Flat	Mar. 25, '03	4,493	54,525	.45	8.79	+3.49
"	Yadkin	Salisbury	Mts	Foot-hills.	Mar. 24, "	3,399	76,200	.83	8.66	+4.44
"	"	Wilkesboro	"	Mts	Oct. 8, "	498	6,220	.46	9.91	+3.89
S. C.	Catawba	Catawba	Flat	Flat	Aug. 8, '04	1,514	24,850	.61	11.30	+6.34
"	Wateree	Camden	"	"	July 15, '05	2,635	29,640	.42	5.10	+0.06
"	Catawba	Rockhill	"	"	Mar. 24, '03	2,987	93,000	1.15	9.18	+4.28
"	"	Morgantown	"	"	June 6, "	758	17,040	.84	5.96	+0.97
"	Broad	Alston	Foot-hills.	Flat	" 7, "	4,609	130,500	1.04	6.97	+3.09
"	Saluda	Waterloo	"	"	" 8, "	1,056	18,970	.67	9.06	+3.72
"	Savannah	Calhoun Falls	Mts	Foot-hills.	" 7, "	2,712	57,405	.79	7.77	+3.76
Fla.	Suwanee	White Springs	Flat	Flat	July .. '06	1,737	9,490	.22	9.59	+1.82
Ga.	Flint	Albany	Foot-hills.	Flat	Feb. 17, '03	5,000	35,900	.27	......	......
"	Oconee	Dublin	"	"	" 12, "	4,182	34,920	.31	5.12	−1.40

RECORD NO. 15—Continued

State	River	Gage Station	Character of Watershed		Date of Flood	Drainage Area Sq. Mile	Discharge Sec. Ft.	Runoff Inches Depth per 24 Hours	Rainfall	
			Upper End	Lower End					Monthly Ins.	Excess Over Normal Ins.
Ga.	Apalachee	Buckhead	Mts.	Foot-hills.	Fcb. 12, '03	440	4,485	.38	10.69	+5.39
"	Ocmulgee	Flovilla	"	"	Sept. 16, "	1,500	6,630	.16	4.95	+2.49
"	Alcovy	Covington	"	"	Mar. 24, "	1,228	1,410	.23	6.66	+1.71
"	Flint	Woodburg	"	"	Feb. 8, "	988	25,750	.97	10.63	......
"	Chattahoochee	West Point	"	Mts.	" 9, "	3,300	66,090	.75	13.69	......
"	"	Oakdale	"	"	" 12, "	1,560	43,900	1.07	13.48	......
"	"	Gainesville	"	"	Mar. 23, "	544	15,430	1.05	12.17	+5.46
"	Coosa	Rome	"	"	Feb. 18, "	4,006	56,347	.52	13.45	+8.78
"	Etowah	"	"	"	July 14, "	11,854	11,200	.22	13.45	+8.78
"	"	Canton	"	"	Feb. 17, "	604	15,181	.93	10.79	+5.83
"	Cossawattee	Carters	"	"	" 28, "	531	14,430	1.01	11.96	+7.61
"	Savannah	Augusta	"	Foot-hills.	" 9, "	7,294	130,400	.68	11.35	+5.96
Ala.	Cahoba	Centerville	Mts.	Mts.	Feb. 8, '03	1,040	12,195	.44	14.94	+10.73
"	Alabama	Selma	"	Foot-hills.	" 15, "	15,400	136,350	.33	12.54	+6.26
"	Tallapoosa	Sturdevant	"	Mts.	" 28, "	2,500	27,370	.41	11.42	
"	Hilsbee	Alexander	"	"	May 15, "	214	4,925	.86	5.40	
"	Talladega	Nottingham	"	"	Feb. 28, "	156	3,592	.86	11.46	+5.41
"	Coosa	Riverside	"	"	" 17, "	7,065	67,500	.35	8.88	+3.72
"	Black Warrior	Cordova	"	"	" 17, "	1,900	42,950	.84	12.01	
"	Broad	Carlton	"	"	Mar. 24, "	762	24,400	1.19	7.04	+0.57
Tex.	Trinity	Riverside	Flat	Flat	Mar. 10, '03	16,000	27,270	.06	5.97	+2.46
"	Brazos	Waco	Foot-hills.	"	Feb. 27, "	30,750	39,650	.05	6.19	+4.26
"	"	Richmond	"	"	Mar. 6, "	44,000	66,550	.06	5.97	+2.46

the movement of the latter through the soil and over the surface is slower and more uniform.

Third, **size and shape.** In general, the ratio of drainage to rainfall is less for large areas than for small, because the rain may not be uniform over the whole; because more time is required for water to reach the main channel from the more distant parts so that the flood portion of a part of the territory may have passed off before the other part arrives; and because a larger part passes away in evaporation. The ratio is greater from long and narrow districts than from broad ones, since the water finds its way to the channel quickly from each side. The topography may materially modify these conditions. If the land at the upper portion of the district is comparatively level and that at the lower is hilly, the crest of flow, after a heavy precipitation, will pass from the lower before that from the upper arrives. This is not true, however, when long periods of precipitation occur.

Fourth, **character and culture of the land.** Undulating or rolling lands which have a hard and smooth surface, like meadows and pastures, give a larger runoff than cultivated fields. If hilly lands are terraced or underdrained so as to conserve a part of the water and distribute the surplus evenly down the slope, the drainage coefficient will be less than if no care in that regard is exercised.

After the above points have been determined, compare districts which most nearly resemble the one under consideration whose drainage runoff has been ascertained, and select a coefficient for computing the size of the outlet ditch. Consider the several large sections of the whole separately with respect to the amount of runoff and the manner in which it is brought to the main, and adjust the tributary ditches to the esti-

mated runoff of the several parts. The distributing effect of time in the movement of the water to the main, and the area of each section, should receive their proper weight.

Drainage Curves. The foregoing discussion of runoff measurements suggests that the relation between the areas and the amount of drainage they require may be expressed graphically by a curve. This could be done for any given section with reasonable accuracy, provided measurements could be made for a series of years at different points in the area. The data required to construct such a curve are the area drained by a single channel, the record of rainfall, and measurements of actual discharge at different points along the channel where the drainage of a known part of the whole must pass. The discharge from the corresponding areas may then be plotted to a scale and a curve made to pass through three or more of the points.

Fig. 42 represents a curve constructed for areas ranging from 4 to 200 square miles. The data were collected from different level areas in the north Mississippi Valley, which have absorptive and easily drained soils. It does not represent the runoff conditions of rolling lands, but from level lands which are well provided with drains. The smaller area requires much the larger relative capacity of drainage ditches to meet the needs of farm land, as, for example, the drainage coefficient is ½ inch for 4 square miles and ¼ inch for 40 square miles. As has been noted, the drainage coefficient for small areas in the same section which are well tile-drained is about ¼ inch on account of the large storage capacity made possible by this method of draining.

Fig. 43 represents data collected on areas in north central Illinois for maximum runoff. Curve A represents the drainage from 200 square miles and lesser

areas in the same part of the State. The upper part of the curve represents the capacity of the ditches which have been constructed instead of the amount of drain-

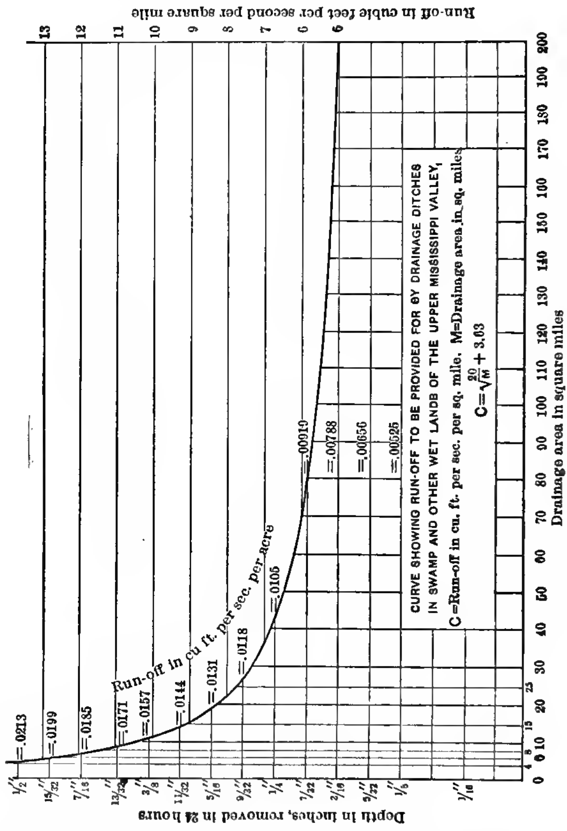

Fig. 42.—Drainage Curve No. 1.

age, since they are the outlets for tile systems where it is desired that the ditches never run full. Curve B more nearly represents the flood capacity required for satisfactory drainage.

It seems evident that each different area has its own drainage curve and, further, that this will take varying forms under different climatic conditions, and that

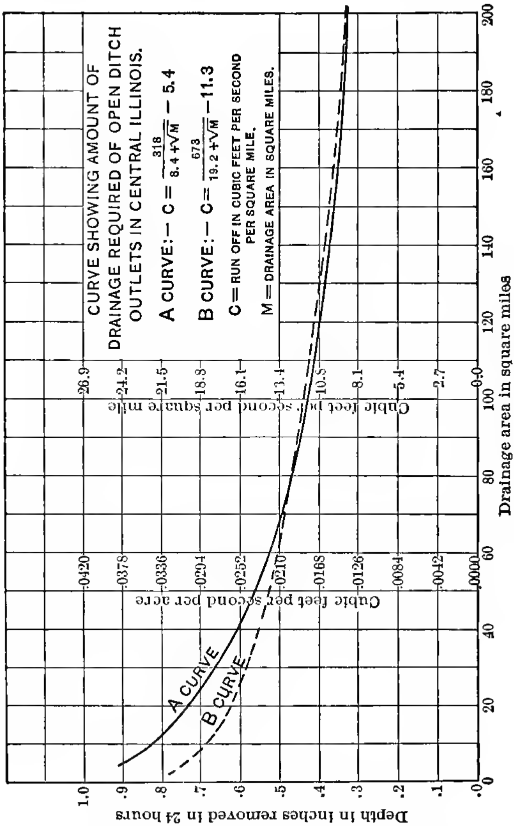

FIG. 43.—DRAINAGE CURVE NO. 2.

it will be modified by surface changes incident to the development of a country. For example, the runoff from a country through natural watercourses only is represented by a curve which more nearly approaches a

straight line than one drained by a well-arranged system of artificial ditches.

Greater precipitation requires greater drainage capacity where the conditions in other respects are the same, but the law of flow is similar. For this reason data which are particularly adapted to one section will be helpful to the engineer in planning drains for another, if he gives due weight to the differences between the two.

CHAPTER XIV

LOCATION AND CONSTRUCTION OF OPEN DITCHES

WITH the preliminary work done, its results considered, and a suitable plan of drainage adopted and outlined upon the map, the engineer is ready for laying out the system upon the ground.

The survey for a ditch, after an approximate location, consists of staking the center line, locating it with reference to property boundaries, and taking levels from which the grade and amount of excavation can be computed. It may begin at either the upper or lower end, the latter usually being preferable. Where State drainage laws specify the place of beginning and manner of staking, the method prescribed should, of course, be followed in those States.

Staking the Line. Ditches and drains pertain to the land through which they pass, and the center line should be tied by measurements to the property lines, the length of ditch on each property being indicated on the final map.

Start from the initial point and run the line with either compass or transit, measuring it with field steel tape or chain, and setting temporary stakes at each 100 feet, numbered consecutively. If the ground is level, as in swamps, river bottoms, etc., also set on the center line permanent stakes with hubs at 300 feet intervals, and at intermediate points where the line changes direction, or where property lines are intersected, the distance from these points to the nearest

property corner being measured and noted. These measurements will prove important later in adjusting assessments for benefits and damages. It is more essential that the location of the ditch with reference to property lines and corners be represented than that the azimuth of the line or its magnetic bearing be correctly ascertained. Levels should be referred to the datum established for the district in the preliminary survey, and the entire system of elevations should be carefully checked as the work proceeds.

If the district is large there may be a location party, with level party following, thus hastening the engineering work. When it is practicable, the entire instrument work connected with the location should be done by the same engineer, who should also be the one to establish the grade. A personal familiarity with the ground along which the line runs is of great assistance in designing drainage works, and in the ready interpretation of survey notes. Bench-marks should be established at convenient points about 75 feet from the line, for use in testing the grade of the ditch after its completion or for continuing levels elsewhere in the district. These should be definitely marked and clearly described in the notes and a liberal number of them should appear on the map and also upon the profile. A convenient method of designating bench-marks is to number them consecutively as B M No. 1, B M No. 2, etc., in connection with the correct elevation of each; and if there are two or more instrument men, the initials of the one setting the B M should appear on it also. These, as well as the numbers of the center stakes, should be marked with red keel pencils.

Establishing the Grade. Where the land is level and the general topography is simple, the grade of the ditch can be run in on the field-book and the depths

and the excavation be computed direct, but the better way is to reduce the level-notes to profile form and determine the grade-line as directed in Chap. VI. If the center line does not represent the general surface of the land, the true surface-line should also be plotted, so that its relation to the grade-line may be seen.

To decide what will constitute a satisfactory grade involves a consideration not only of the requirements of the ditch, but also of the nature of the earth. Grades are limited by nature and we can only adjust and use them. The most essential part of the work is to get an outlet and such depth as will serve the land through which the ditches pass. The grade should then be made as uniform as practicable, and may be as small as 6 inches to 12 inches per mile for gravity ditches, and 0 to 3 inches per mile for ditches used in draining by pumps. Ditches with grades not exceeding 3 feet per mile can be kept in repair more cheaply than those with steeper grades because the banks are not injured by erosion and the velocity of the water is sufficient to make them at least partially self-cleaning.

Depth of Ditches. The topography of the land through which a ditch passes naturally governs largely the depth it shall have. For efficiency and economy of construction, ditches from 6 to 12 feet deep are desirable. The former, if sand and gravel are found in the bottom, and the latter in lands with clay subsoil. The construction of ditches exceeding 12 feet in depth is quite often attended with difficulty and additional expense, and should not be recommended until a thorough examination of the earth has been made by borings, so that the material to be encountered can be safely predicted. There are limitations to depth which are

dependent upon efficiency, first cost, and maintenance, that should be first determined for the area.

Computing the Size. Ascertain the total area to be drained in either acres or square miles; multiply this area by the runoff in second feet corresponding to the drainage coefficient for the area selected from **Table III.** The result will be the number of cubic feet per second which the channel will be required to discharge at the outlet. Assume a channel of estimated section, the grade and depth having been previously determined, and compute its discharge by substituting the proper values in Kutter's formula (**No. 12**) or Elliott's formula (**No. 13**). When Kutter's is used, it should be observed that the result obtained will vary greatly according to the value of n which may be selected. If the value of Q for the ditch of the assumed size does not correspond to the required discharge, the size should be increased or diminished until the required capacity is obtained.

In a similar manner the cross-section at various other points along the channel should be computed, particularly where there are material changes in grade or where large branches or tributary streams enter. Good judgment should be exercised in adjusting the size of ditches to different parts of the area, since physical conditions of surface and soil should be taken into consideration, and also the fact that the drainage coefficient does not provide for unusual storms which occur at long intervals in some localities.

Illustrative Example. A level district of 50 square miles is to be drained through one channel 8 feet deep, with grade of one foot per mile. If the channel has side slopes of ½ to 1 what should be the bottom width at the outlet when a drainage coefficient of ½ inch is used?

13.44 sec. feet $\times$ 50 = 672 sec. feet = required value of Q.

Assume a bottom 25 feet wide. Work by Kutter's formula (No. 12).

$$a = 232$$
$$p = 43$$
$$r = \frac{a}{p} = 5.40 \qquad v = 80\sqrt{\frac{232}{43} \times .0002} = 2.63$$
$$n = .025$$
$$c = 80 \qquad Q = 232 \times 2.63 = 610 \text{ sec. ft.}$$
$$s = 1.056 \text{ ft. per mi.} = .0002$$

In a similar manner, computing the discharge of a ditch with bottom 28 feet wide we would get a result of 686 cu. ft., which nearly meets the required conditions. If it is not desired to have the channel flow full at ordinary flood times it will be best to use a ditch with 30 ft. bottom. Should we use .0225 as a value for n, which would be about the right factor if the channel were in clay land and kept in good condition, the discharge of the ditch with 25 ft. bottom would be 675 sec.-ft., or the amount required for the area.

The trial method is used because the formula becomes too unwieldy if arranged to give size of channel direct.

Taking up the same problem and working it by Elliott's formula (No. 13), we have the following:

$$a = 232$$
$$p = 43 \qquad v = \sqrt{\frac{232}{43} \times 1.58} = 2.92$$
$$1\tfrac{1}{2}\,h = 1.58$$
$$Q = 677$$

Assuming that while we have a ditch 8 feet deep we wish to have the maximum flow only .8 of the depth of the channel, and computing the trial channel with 30 ft. bottom, and depth of flow 6.4 feet, we have the following:

$$a = 212$$
$$p = 44.3 \qquad v = \sqrt{\frac{233}{44.3} \times 1.58} = 2.75$$
$$1\tfrac{1}{2}\,h = 1.58$$
$$Q = 212 \times 2.75 = 583$$

A ditch of such capacity would carry the water at a permanently lower level than the others, and would also provide for an unusual flood flow.

Side Slopes. The liability of earth to slump or slip in many localities where ditches are to be made, makes it necessary to construct them sometimes with side slopes as flat as 1½ to 1, or 2 to 1 to make them permanent. The other alternative is to make the excavation large enough to permit the sides to cave and take their ultimate slope, and leave a clear ditch of the specified size. The latter is, perhaps, the more economical method to pursue if one can predict the behavior of the

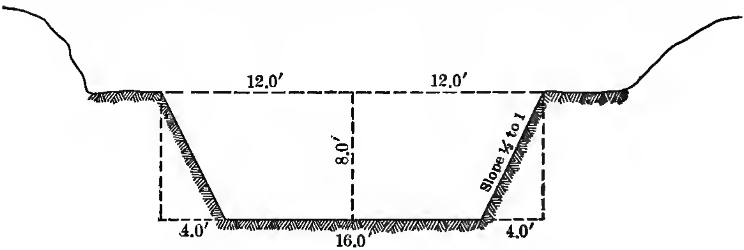

FIG. 44.—SIDE-SLOPES ½ TO 1.

earth after it is excavated. The superiority of a slope constructed as it is desired to have it remain cannot be denied, and it should be so made if it is practicable. Slopes as ordinarily constructed by the floating dredge are ½ to 1 or nearly vertical, as shown in Fig. 44. Stiff clays stand well at that slope and lands which are somewhat loose in structure do not cave badly unless the ditches are deep. The engineer should make sufficient examination by borings or otherwise, to enable him to determine what slope of banks should be specified.

Berm. A wide berm will lessen the risk of caving banks since the earth of the waste banks is deposited at such a distance from the ditch that their weight will

not cause the sides of the ditch to be displaced. Ordinarily a clear berm of 10 feet between the edge of the ditch and the foot of the waste bank is sufficient. If the excavation is made through a soft marsh, a greater distance may be found necessary.

Dimensions of Small Ditches. Another factor besides carrying capacity enters into the design of the size of small outlet ditches, and that is their economic construction and subsequent maintenance. A minimum bottom width of 4 feet, or of 3 feet where the grade exceeds 4 feet per mile, is approximately correct, depending much upon climate and earth conditions. The reasons for such limitations are as follows. It is impracticable to make ditches with narrower bottoms or to clean them out except by hand labor. This should always be avoided as far as possible. The continual silting of ditches on light grades is a contingency that must be recognized in their maintenance. An amount of silt or the caving of the sides which would place a barrier a foot deep across an 18-inch bottom would cause little injury to a four-foot bottom, and could be removed more easily.

There is a noticeable difference in this regard between ditches in cold and those in warm climates. Alternate freezing and thawing causes the sides of ditches to crumble and slough off, thereby materially contributing to the silt deposit which tends to obstruct the flow in small ditches. This is not the case in southern climates, so that we find the ditches in many instances maintaining almost vertical sides, and silting is due to water action alone. As a matter of economy in land surface, cost of construction and efficiency of operation, ditches should have as steep side slopes as can be maintained. For the same reason the waste banks which are often left rough and become covered with useless vegetation

should be leveled and utilized, with the exception of a narrow border of 3 feet on each bank, which should be laid in grass to keep the banks intact. These features should be considered by the engineer since they are important in the design and construction of the smaller outlet drainage works. In passing, it may be suggested that large tile drains may, in many cases, be substituted for such ditches.

Cross-Sectioning. If the ground is a plane surface, quite uniformly level, center line elevations are suffi-

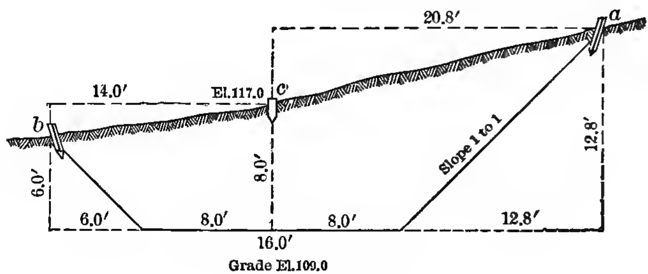

FIG. 45.—SETTING SLOPE-STAKES.

cient for computing the excavation, with hubs at the points mentioned under **Staking the Line.** The top width can be set off from the center stake by direct measurement, and marked on either side by stakes called slope-stakes. If the side slopes are 1 horizontal to 1 vertical the distance out on either side of the center is ½ the bottom width plus the depth; if 1½ to 1, it is ½ the bottom width plus 1½ times the depth, etc., or, in general, one half the bottom width plus the product of the depth by the rate of slope.

When the ground is uneven, a method called cross-sectioning must be resorted to for determining the position of slope-stakes, and securing measurements for

computing excavation. The process is as follows: The grade elevation at each station having been determined and entered in the field-book, set up the level at a convenient point for taking observations on several stations. Obtain height of instrument from nearest bench. Have the rod set at an estimated distance out as **a**, **Fig. 45**; find elevation, and from it subtract the grade elevation which in the example is 109.0. If the side slope is 1 to 1 the distance out will be $8 + 12.8 = 20.8$. The rodman, with the end of tape at **c**, measures the distance **c a**. If it is 20.8, the stake is driven and the

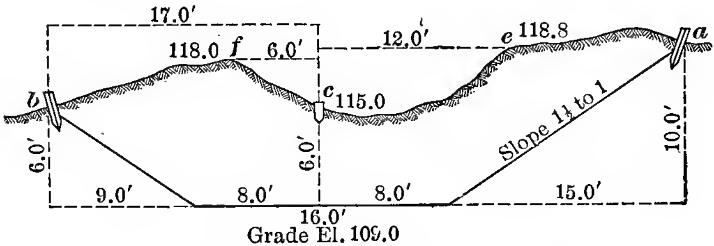

FIG. 46.—SLOPE-STAKES ON UNEVEN GROUND.

distance and cut are recorded in the notes. If not, another trial should be made. The rodman then estimates the elevation at **b**, a level is taken, and the distance from **c** determined in the same manner as that for **a**. In the example, the elevation of **b** = 115.0 and the depth at **b** = 6. **c b** = 8 + 6 = 14.0. Whatever the side slopes may be, the same method is employed, observing the rule before given for computing top width. If an allowance is to be made for an old ditch or channel which will necessitate a deduction in computing excavation, levels should be taken at **e** and **f**, **Fig. 46**, so that the sectional area of the existing channel can be computed and deducted from the whole section. The slope

stakes having been set, the contractor may begin at the limit indicated by them and extend the required slope to the depth indicated on the center stake, which will give the ditch the bottom width that has been designated.

Keeping Cross-Section Notes. In order that the notes from which excavation is to be computed be kept free from all possibility of confusion, the elevation of each station on the center-line and that of the grade-line should be transferred to another page of the field-book, and headed **Cross-Section of Drain No.—from Sta.—to Sta.—** The form is arranged for recording the elevation of the ground at each slope-stake, indicated as **Right** and **Left** as the survey proceeds up grade, the distance of each from the center, and the number of cubic yards of excavation when the computation has been made.

FORM FOR CROSS-SECTION BOOK. (Left-hand page.)

Sta	−S	Elev	G L	C Cut	R Cut	L Cut	Dist. Out		Cu. Yds.
							R	L	
21	H I 126.2	117.0	109.0	8.0	..	..	..	..	
R	4.4	121.8	..	..	12.8	..	20.8	..	
L	11.2	115.0	..	..	..	6.0	..	14.0	
22	....	....	....	....	....	....	....	....	
R	....	....	....	....	....	....	....	....	
L	....	....	....	....	....	....	....	....	

The computations for obtaining the height of instrument are made on the right-hand page of the book, since the H I may be obtained by taking a backsight on the bench-mark or center stake, whichever is most convenient.

Computing Excavation. The usual method of computing excavation for ditches is by end areas, which is as follows: Add the end areas of any given section, divide by two and obtain as a result the mean area.

Multiply this result by the length of the section and divide by 27; the result will be the number of cubic yards in the station. There are many tables and diagrams in use which greatly expedite and lessen the labor of such computation. The following **Excavation and Embankment Table** (Table XIV) is regarded by the author as having a more general application to the work of the drainage engineer than many others. It is adapted to general use in all classes of ditch and levee work. It gives the number of cubic yards in a station of 100 feet when the mean cross-sectional area is known. To use the table proceed as follows: Having the mean end area, turn to the column headed **Area in feet,** and find the corresponding number. Opposite this will be found the number of cubic yards in a length of 100 feet. If the area has a decimal part pass the eye to the right and take the number of yards in the column under the decimal corresponding to the one required. If the number of yards for only a part of a station is required, take such a part of the tabular number given as the required length is of 100 feet.

Illustrative examples. The mean area of a 100-ft. section is 133. How many cubic yards of excavation are required? Find 133 in the left-hand column and opposite under the 0 column is 492.59, the number of cubic yards. Suppose the mean area of a 100 ft. section is 119.6. Find 119 in the left-hand column, pass to the right, and in the column headed .6 will be found 442.96, the number of cubic yards.

To find the yardage for areas larger than those given in the table, find the cubic yards for half the required area and multiply by two. **Example.**—If the mean area is 642.4, the cubic yards will be the number corresponding to 321.2 (1189.63) multiplied by 2 = 2379.26 = cubic yards required.

Another method of using the table when the areas are larger than those provided for by the table, and do not exceed 3599, is the following: Point off one place from the whole number as decimal and find the cubic yards for that number; then remove the decimal point one place to the right; the result is the number of yards required. If there is a fraction, find from the table the number of yards in the fraction and add it to the yardage obtained from the whole number area.

Taking the above example 642.4 and removing the decimal point one place to the left, we have 64.2; the number of yards corresponding to this area is 237.78. Removing the point one place to the right we have 2377.8. Adding to this 1.48 the number of yards corresponding to .4, we have 2379.28 cubic yards.

As the several stations are computed, enter the results in the note-book opposite the respective station in the column headed for that use.

Right of Way. Crossing public highways and railroads often delays the progress of the work because of failure to make necessary and timely arrangements with the authorities who control the respective rights of way. Highway bridges along the line must be removed in advance, and replaced after the channel has been excavated. This is done by the contractor at the expense of the district in some States, and by the county road authorities in others. Facilities for securing the proper grade should be given the contractor at such places, so that he will make no mistake, and the earth should be deposited where it will best accommodate the interests of the highway.

In crossing railroad rights of way there must be cordial cooperation between engineer, contractor, and railroad company, for while the latter must guard its important traffic interests, the delay of the work should

TABLE XIV

Excavation and Embankment

Area in Feet	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
0	0.00	0.37	0.74	1.11	1.48	1.85	2.22	2.59	2.96	3.33
1	3.70	4.07	4.45	4.81	5.19	5.56	5.93	6.30	6.67	7.04
2	7.41	7.78	8.15	8.52	8.89	9.26	9.63	10.00	10.37	10.74
3	11.11	11.48	11.85	12.22	12.59	12.96	13.33	13.70	14.07	14.44
4	14.82	15.19	15.56	15.93	16.30	16.67	17.04	17.41	17.78	18.15
5	18.52	18.89	19.26	19.63	20.00	20.37	20.74	21.11	21.48	21.85
6	22.22	22.59	22.96	23.33	23.70	24.07	24.44	24.82	25.19	25.56
7	25.93	26.30	26.67	27.04	27.41	27.78	28.15	28.52	28.89	29.26
8	29.63	30.00	30.37	30.74	31.11	31.48	31.85	32.22	32.59	32.96
9	33.33	33.70	34.07	34.44	34.82	35.19	35.56	35.93	36.30	36.67
10	37.04	37.41	37.78	38.15	38.52	38.89	39.26	39.63	40.00	40.37
11	40.74	41.11	41.48	41.85	42.22	42.59	42.96	43.33	43.70	44.07
12	44.44	44.82	45.19	45.56	45.93	46.30	46.67	47.04	47.41	47.78
13	48.15	48.52	48.89	49.26	49.63	50.00	50.37	50.74	51.11	51.48
14	51.85	52.22	52.59	52.96	53.33	53.70	54.07	54.44	54.82	55.19
15	55.56	55.93	56.30	56.67	57.04	57.41	57.78	58.15	58.52	58.89
16	59.26	59.63	60.00	60.37	60.74	61.11	61.48	61.85	62.22	62.59
17	62.96	63.33	63.70	64.07	64.44	64.82	65.19	65.56	65.93	66.30
18	66.67	67.04	67.41	67.78	68.15	68.52	68.89	69.26	69.63	70.00
19	70.37	70.74	71.11	71.48	71.85	72.22	72.59	72.96	73.33	73.70
20	74.07	74.44	74.82	75.19	75.56	75.93	76.30	76.67	77.04	77.41
21	77.78	78.15	78.52	78.89	79.26	79.63	80.00	80.37	80.74	81.11
22	81.48	81.85	82.22	82.59	82.96	83.33	83.70	84.07	84.44	84.82
23	85.19	85.56	85.93	86.30	86.67	87.04	87.41	87.78	88.15	88.52
24	88.89	89.26	89.63	90.00	90.37	90.74	91.11	91.48	91.85	92.22
25	92.59	92.96	93.33	93.70	94.07	94.44	94.82	95.19	95.56	95.93
26	96.30	96.67	97.04	97.41	97.78	98.15	98.52	98.89	99.26	99.63
27	100.00	100.37	100.74	101.11	101.48	101.85	102.22	102.59	102.96	103.33
28	103.70	104.07	104.44	104.82	105.19	105.56	105.93	106.30	106.67	107.04
29	107.41	107.78	108.15	108.52	108.89	109.26	109.63	110.00	110.37	110.74
30	111.11	111.48	111.85	112.22	112.59	112.96	113.33	113.70	114.07	114.44
31	114.81	115.18	115.56	115.92	116.29	116.67	117.03	117.40	117.77	118.15
32	118.52	118.89	119.26	119.63	120.00	120.37	120.74	121.11	121.48	121.85
33	122.22	122.59	122.96	123.33	123.70	124.07	124.44	124.81	125.18	125.55
34	125.92	126.30	126.66	127.03	127.40	127.77	128.14	128.51	128.88	129.26
35	129.63	130.00	130.37	130.74	131.11	131.48	131.85	132.22	132.59	132.96
36	133.33	133.70	134.07	134.44	134.81	135.18	135.55	135.92	136.29	136.67
37	137.04	137.41	137.78	138.15	138.52	138.89	139.26	139.63	140.00	140.37
38	140.74	141.11	141.48	141.85	142.22	142.59	142.96	143.33	143.70	144.07
39	144.44	144.81	145.18	145.55	145.92	146.29	146.66	147.03	147.40	147.78
40	148.15	148.52	148.89	149.26	149.63	150.00	150.37	150.74	151.11	151.48
41	151.85	152.22	152.59	152.96	153.33	153.70	154.07	154.44	154.81	155.18
42	155.55	155.92	156.29	156.66	157.03	157.40	157.77	158.14	158.51	158.89
43	159.26	159.63	160.00	160.37	160.74	161.11	161.48	161.85	162.22	162.59

TABLE XIV—Continued

Area in Feet	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
44	162.96	163.33	163.70	164.07	164.44	164.81	165.18	165.55	165.92	166.30
45	166.67	167.04	167.41	167.78	168.15	168.52	168.89	169.26	169.63	170.00
46	170.37	170.74	171.11	171.48	171.85	172.22	172.59	172.96	173.33	173.70
47	174.07	174.44	174.81	175.18	175.55	175.92	176.29	176.66	177.03	177.41
48	177.78	178.15	178.52	178.89	179.26	179.63	180.00	180.37	180.74	181.11
49	181.48	181.85	182.22	182.59	182.96	183.33	183.70	184.07	184.44	184.81
50	185.18	185.55	185.92	186.29	186.66	187.03	187.40	187.77	188.14	188.52
51	188.89	189.26	189.63	190.00	190.37	190.74	191.11	191.48	191.85	192.22
52	192.59	192.96	193.33	193.70	194.07	194.44	194.81	195.18	195.55	195.93
53	196.30	196.67	197.04	197.41	197.78	198.15	198.52	198.89	199.26	199.63
54	200.00	200.37	200.74	201.11	201.48	201.85	202.22	202.59	202.96	203.33
55	203.70	204.07	204.44	204.81	205.18	205.55	205.92	206.29	206.66	207.03
56	207.41	207.78	208.15	208.52	208.89	209.26	209.63	210.00	210.37	210.74
57	211.11	211.48	211.85	212.22	212.59	212.96	213.33	213.70	214.07	214.44
58	214.81	215.18	215.55	215.92	216.29	216.66	217.03	217.40	217.77	218.15
59	218.52	218.89	219.26	219.63	220.00	220.37	220.74	221.11	221.48	221.85
60	222.22	222.59	222.96	223.33	223.70	224.07	224.44	224.81	225.18	225.55
61	225.92	226.29	226.66	227.03	227.40	227.77	228.14	228.51	228.88	229.26
62	229.63	230.00	230.37	230.74	231.11	231.48	231.85	232.22	232.59	232.96
63	233.33	233.70	234.07	234.44	234.81	235.18	235.55	235.92	236.29	236.67
64	237.04	237.41	237.78	238.15	238.52	238.89	239.26	239.63	240.00	240.37
65	240.74	241.11	241.48	241.85	242.22	242.59	242.96	243.33	243.70	244.07
66	244.44	244.81	245.18	245.55	245.92	246.30	246.67	247.04	247.41	247.78
67	248.15	248.52	248.89	249.26	249.63	250.00	250.37	250.74	251.11	251.48
68	251.85	252.22	252.59	252.96	253.33	253.70	254.07	254.44	254.81	255.18
69	255.56	255.93	256.30	256.67	257.04	257.41	257.78	258.15	258.52	258.89
70	259.26	259.63	260.00	260.37	260.74	261.11	261.48	261.85	262.22	262.59
71	262.96	263.33	263.70	264.07	264.44	264.81	265.18	265.55	265.92	266.30
72	266.67	267.04	267.41	267.78	268.15	268.52	268.89	269.26	269.63	270.00
73	270.37	270.74	271.11	271.48	271.85	272.22	272.59	272.96	273.33	273.70
74	274.07	274.44	274.81	275.18	275.55	275.92	276.29	276.66	277.04	277.41
75	277.78	278.15	278.52	278.89	279.26	279.63	280.00	280.37	280.74	281.11
76	281.48	281.85	282.22	282.59	282.96	283.33	283.70	284.07	284.44	284.81
77	285.18	285.56	285.93	286.30	286.67	287.04	287.41	287.78	288.15	288.52
78	288.89	289.26	289.63	290.00	290.37	290.74	291.11	291.48	291.85	292.22
79	292.59	292.96	293.33	293.70	294.07	294.44	294.81	295.18	295.55	295.93
80	296.30	296.67	297.04	297.41	297.78	298.15	298.52	298.89	299.26	299.63
81	300.00	300.37	300.74	301.11	301.48	301.85	302.22	302.59	302.96	303.33
82	303.70	304.07	304.44	304.81	305.18	305.55	305.92	306.29	306.66	307.03
83	307.41	307.78	308.15	308.52	308.89	309.26	309.63	310.00	310.37	310.74
84	311.11	311.48	311.85	312.22	312.59	312.96	313.33	313.70	314.07	314.44
85	314.81	315.19	315.56	315.93	316.30	316.67	317.04	317.41	317.78	318.15
86	318.52	318.89	319.26	319.63	320.00	320.37	320.74	321.11	321.48	321.85
87	322.22	322.59	322.96	323.33	323.70	324.07	324.44	324.81	325.18	325.55
88	325.92	326.30	326.67	327.04	327.41	327.78	328.15	328.52	328.89	329.26
89	329.63	330.00	330.37	330.74	331.11	331.48	331.85	332.22	332.59	332.96

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
90	333.33	333.70	334.07	334.44	334.81	335.18	335.55	335.92	336.29	336.67
91	337.04	337.41	337.78	338.15	338.52	338.89	339.25	339.62	339.99	340.37
92	340.74	341.11	341.48	341.85	342.22	342.59	342.96	343.33	343.70	344.07
93	344.44	344.81	345.18	345.56	345.93	346.30	346.67	347.03	347.40	347.78
94	348.15	348.52	348.89	349.26	349.63	350.00	350.37	350.74	351.11	351.48
95	351.85	352.22	352.59	352.96	353.33	353.70	354.07	354.44	354.81	355.18
96	355.55	355.93	356.30	356.67	357.04	357.41	357.78	358.15	358.52	358.89
97	359.26	359.63	360.00	360.37	360.74	361.11	361.48	361.85	362.22	362.59
98	362.96	363.33	363.70	364.07	364.44	364.81	365.18	365.55	365.93	366.30
99	366.67	367.04	367.41	367.78	368.15	368.52	368.89	369.26	369.63	370.00
100	370.37	370.74	371.11	371.48	371.85	372.22	372.59	372.96	373.33	373.70
101	374.07	374.44	374.81	375.18	375.55	375.92	376.29	376.67	377.04	377.41
102	377.78	378.15	378.52	378.89	379.26	379.63	380.00	380.37	380.74	381.11
103	381.48	381.85	382.22	382.59	382.96	383.33	383.70	384.07	384.44	384.81
104	385.18	385.55	385.92	386.29	386.67	387.04	387.41	387.78	388.15	388.52
105	388.89	389.26	389.63	390.00	390.37	390.74	391.11	391.48	391.85	392.22
106	392.59	392.96	393.33	393.70	394.07	394.44	394.81	395.18	395.55	395.92
107	396.30	396.67	397.04	397.41	397.78	398.15	398.52	398.89	399.26	399.63
108	400.00	400.37	400.74	401.11	401.48	401.85	402.22	402.59	402.96	403.33
109	403.70	404.07	404.44	404.81	405.18	405.55	405.92	406.29	406.67	407.04
110	407.41	407.78	408.15	408.52	408.89	409.26	409.63	410.00	410.37	410.74
111	411.11	411.48	411.85	412.22	412.59	412.96	413.33	413.70	414.07	414.44
112	414.81	415.18	415.55	415.92	416.29	416.67	417.04	417.41	417.78	418.15
113	418.52	418.89	419.26	419.63	420.00	420.37	420.74	421.11	421.48	421.85
114	422.22	422.59	422.96	423.33	423.70	424.07	424.44	424.81	425.18	425.56
115	425.93	426.30	426.67	427.04	427.41	427.78	428.15	428.52	428.89	429.26
116	429.63	430.00	430.37	430.74	431.11	431.48	431.85	432.22	432.59	432.96
117	433.33	433.70	434.07	434.44	434.81	435.18	435.55	435.92	436.29	436.67
118	437.04	437.41	437.78	438.15	438.52	438.89	439.26	439.63	440.00	440.37
119	440.74	441.11	441.48	441.85	442.22	442.59	442.96	443.33	443.70	444.07
120	444.44	444.81	445.18	445.55	445.92	446.29	446.67	447.04	447.41	447.78
121	448.15	448.52	448.89	449.26	449.63	450.00	450.37	450.74	451.11	451.48
122	451.85	452.22	452.59	452.96	453.33	453.70	454.07	454.44	454.81	455.18
123	455.55	455.92	456.29	456.67	457.04	457.41	457.78	458.15	458.52	458.89
124	459.26	459.63	460.00	460.37	460.74	461.11	461.48	461.85	462.22	462.59
125	462.96	463.33	463.70	464.07	464.44	464.81	465.18	465.55	465.93	466.30
126	466.67	467.04	467.41	467.78	468.15	468.52	468.89	469.26	469.63	470.00
127	470.37	470.74	471.11	471.48	471.85	472.22	472.59	472.96	473.33	473.70
128	474.07	474.44	474.81	475.18	475.56	475.93	476.30	476.67	477.04	477.41
129	477.78	478.15	478.52	478.89	479.26	479.63	480.00	480.37	480.74	481.11
130	481.48	481.85	482.22	482.59	482.96	483.33	483.70	484.07	484.44	484.81
131	485.18	485.55	485.92	486.29	486.67	487.04	487.41	487.78	488.15	488.52
132	488.89	489.26	489.63	490.00	490.37	490.74	491.11	491.48	491.85	492.22
133	492.59	492.96	493.33	493.70	494.07	494.44	494.81	495.19	495.56	495.93
134	496.30	496.67	497.04	497.41	497.78	498.15	498.52	498.89	499.26	499.63
135	500.00	500.37	500.74	501.11	501.48	501.85	502.22	502.59	502.96	503.33

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
136	503.70	504.07	504.44	504.81	505.18	505.56	505.93	506.30	506.67	507.04
137	507.41	507.78	508.15	508.52	508.89	509.26	509.63	510.00	510.37	510.74
138	511.11	511.48	511.85	512.22	512.59	512.96	513.33	513.70	514.07	514.44
139	514.81	515.18	515.55	515.92	516.29	516.67	517.04	517.41	517.78	518.15
140	518.52	518.89	519.26	519.63	520.00	520.37	520.74	521.11	521.48	521.85
141	522.22	522.59	522.96	523.33	523.70	524.07	524.44	524.81	525.19	525.56
142	525.93	526.30	526.67	527.04	527.41	527.78	528.15	528.52	528.89	529.26
143	529.63	530.00	530.37	530.74	531.11	531.48	531.85	532.22	532.59	532.94
144	533.33	533.70	534.07	534.44	534.81	535.18	535.56	535.93	536.30	536.67
145	537.04	537.41	537.78	538.15	538.52	538.89	539.26	539.63	540.00	540.37
146	540.74	541.11	541.48	541.85	542.22	542.59	542.96	543.33	543.70	544.07
147	544.44	544.81	545.18	545.56	545.93	546.30	546.67	547.04	547.41	547.78
148	548.15	548.52	548.89	549.26	549.63	550.00	550.37	550.74	551.11	551.48
149	551.85	552.22	552.59	552.96	553.33	553.70	554.07	554.44	554.81	555.18
150	555.55	555.93	556.30	556.67	557.04	557.41	557.78	558.15	558.52	558.89
151	559.26	559.63	560.00	560.37	560.74	561.11	561.48	561.85	562.22	562.59
152	562.96	563.33	563.70	564.07	564.44	564.81	565.18	565.56	565.93	566.30
153	566.67	567.04	567.41	567.78	568.15	568.52	568.89	569.26	569.63	570.00
154	570.37	570.74	571.11	571.48	571.85	572.22	572.59	572.96	573.33	573.70
155	574.07	574.44	574.81	575.18	575.56	575.93	576.30	576.67	577.04	577.41
156	577.78	578.15	578.52	578.89	579.26	579.63	580.00	580.37	580.74	581.11
157	581.48	581.85	582.22	582.59	582.96	583.33	583.70	584.07	584.44	584.81
158	585.18	585.55	585.92	586.29	586.66	587.04	587.41	587.78	588.15	588.52
159	588.89	589.26	589.63	590.00	590.37	590.74	591.11	591.48	591.85	592.22
160	592.59	592.96	593.33	593.70	594.07	594.44	594.81	595.18	595.55	595.92
161	596.29	596.67	597.04	597.41	597.78	598.15	598.52	598.89	599.26	599.63
162	600.00	600.37	600.74	601.11	601.48	601.85	602.22	602.59	602.96	603.33
163	603.70	604.07	604.44	604.81	605.18	605.55	605.92	606.30	606.67	607.04
164	607.41	607.78	608.15	608.52	608.89	609.26	609.63	610.00	610.37	610.74
165	611.11	611.48	611.85	612.22	612.59	612.96	613.33	613.70	614.07	614.44
166	614.81	615.18	615.55	615.92	616.29	616.67	617.04	617.41	617.78	618.15
167	618.52	618.89	619.26	619.63	620.00	620.37	620.74	621.11	621.48	621.85
168	622.22	622.59	622.96	623.33	623.70	624.07	624.44	624.81	625.18	625.56
169	625.93	626.30	626.67	627.04	627.41	627.78	628.15	628.52	628.89	629.26
170	629.63	630.00	630.37	630.74	631.11	631.48	631.85	632.22	632.59	632.96
171	633.33	633.70	634.07	634.44	634.81	635.18	635.55	635.92	636.29	636.66
172	637.04	637.40	637.77	638.14	638.51	638.88	639.25	639.62	639.99	640.37
173	640.74	641.11	641.48	641.85	642.22	642.59	642.96	643.33	643.70	644.07
174	644.44	644.81	645.18	645.55	645.92	646.29	646.66	647.03	647.41	647.78
175	648.15	648.52	648.89	649.26	649.63	650.00	650.37	650.74	651.11	651.48
176	651.85	652.22	652.59	652.96	653.33	653.70	654.07	654.44	654.81	655.18
177	655.56	655.93	656.30	656.67	657.04	657.41	657.78	658.15	658.52	658.89
178	659.26	659.63	660.00	660.37	660.74	661.11	661.48	661.85	662.22	662.59
179	662.96	663.33	663.70	664.07	664.44	664.81	665.18	665.55	665.92	666.29
180	666.67	667.04	667.41	667.78	668.15	668.52	668.89	669.26	669.63	670.00
181	670.37	670.74	671.11	671.48	671.85	672.22	672.59	672.96	673.33	673.70

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
182	674.07	674.44	674.81	675.18	675.55	675.93	676.30	676.67	677.04	677.41
183	677.78	678.15	678.52	678.89	679.26	679.63	680.00	680.37	680.74	681.11
184	681.48	681.85	682.22	682.59	682.96	683.33	684.70	684.07	684.44	684.81
185	685.18	685.56	685.93	686.30	686.67	687.04	687.41	687.78	688.15	688.52
186	688.89	689.26	689.63	690.00	690.37	690.74	691.11	691.48	691.85	692.22
187	692.59	692.96	693.33	693.70	694.07	694.44	694.81	695.18	695.55	695.92
188	696.30	696.67	697.04	697.41	697.78	698.15	698.52	698.89	699.26	699.63
189	700.00	700.37	700.74	701.11	701.48	701.85	702.22	702.59	702.96	703.33
190	703.70	704.07	704.44	704.81	705.18	705.55	705.92	706.29	706.66	707.03
191	707.40	707.77	708.14	708.51	708.89	709.26	709.63	710.00	710.37	710.74
192	711.11	711.48	711.85	712.22	712.59	712.96	713.33	713.70	714.07	714.44
193	714.81	715.18	715.55	715.92	716.29	716.67	717.04	717.41	717.78	718.15
194	718.52	718.89	719.26	719.63	720.00	720.37	720.74	721.11	721.48	721.85
195	722.22	722.59	722.96	723.33	723.70	724.07	724.44	724.81	725.18	725.55
196	725.92	726.29	726.66	727.03	727.40	727.77	728.14	728.51	728.88	729.25
197	729.63	730.00	730.37	730.74	731.11	731.48	731.85	732.22	732.59	732.96
198	733.33	733.70	734.07	734.44	734.81	735.18	735.55	735.93	736.30	736.67
199	737.04	737.41	737.78	738.15	738.52	738.89	739.26	739.63	740.00	740.37
200	740.74	741.11	741.48	741.85	742.22	742.59	742.96	743.33	743.70	744.07
201	744.44	744.81	745.18	745.55	745.93	746.30	746.67	747.04	747.41	747.78
202	748.15	748.52	748.89	749.26	749.63	750.00	750.37	750.74	751.11	751.48
203	751.85	752.22	752.59	752.96	753.33	753.70	754.07	754.44	754.81	755.18
204	755.55	755.93	756.30	756.67	757.04	757.41	757.78	758.15	758.52	758.89
205	759.26	759.63	760.00	760.37	760.74	761.11	761.48	761.85	762.22	762.59
206	762.96	763.33	763.70	764.07	764.44	764.81	765.18	765.55	765.93	766.30
207	766.66	767.04	767.41	767.78	768.15	768.52	768.89	769.26	769.63	770.00
208	770.37	770.74	771.11	771.48	771.85	772.22	772.59	772.96	773.33	773.70
209	774.07	774.44	774.81	775.18	775.55	775.93	776.30	776.66	777.04	777.41
210	777.78	778.15	778.52	778.89	779.26	779.63	780.00	780.37	780.74	781.11
211	781.48	781.85	782.22	782.59	782.96	783.33	783.70	784.07	784.44	784.81
212	785.18	785.55	785.93	786.30	786.66	787.04	787.41	787.78	788.15	788.52
213	788.89	789.26	789.63	790.00	790.37	790.74	791.11	791.48	791.85	792.22
214	792.59	792.96	793.33	793.70	794.07	794.44	794.81	795.18	795.55	795.93
215	796.30	796.66	797.04	797.41	797.78	798.15	798.52	798.89	799.26	799.63
216	800.00	800.37	800.74	801.11	801.48	801.85	802.22	802.59	802.96	803.33
217	803.70	804.07	804.44	804.81	805.18	805.55	805.93	806.30	806.66	807.04
218	807.41	807.78	808.15	808.52	808.89	809.26	809.63	810.00	810.37	810.74
219	811.11	811.48	811.85	812.22	812.59	812.96	813.33	813.70	814.07	814.44
220	814.81	815.18	815.55	815.93	816.30	816.66	817.04	817.41	817.78	818.15
221	818.52	818.89	819.26	819.63	820.00	820.37	820.74	821.11	821.48	821.85
222	822.22	822.59	822.96	823.33	823.70	824.07	824.44	824.81	825.18	825.55
223	825.93	826.30	826.66	827.04	827.41	827.78	828.15	828.52	828.89	829.26
224	829.63	830.00	830.37	830.74	831.11	831.48	831.85	832.22	832.59	832.96
225	833.33	833.70	834.07	834.44	834.81	835.18	835.55	835.93	836.30	836.66
226	837.04	837.41	837.78	838.15	838.52	838.89	839.26	839.63	840.00	840.37
227	840.74	841.11	841.48	841.85	842.22	842.59	842.96	843.33	843.70	844.07

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
228	844.44	844.81	845.18	845.55	845.93	846.30	846.66	847.04	847.41	847.78
229	848.15	848.52	848.89	849.26	849.63	850.00	850.37	850.74	851.11	851.48
230	851.85	852.22	852.59	852.96	853.33	853.70	854.07	854.44	854.81	855.18
231	855.55	855.93	856.30	856.66	857.04	857.41	857.78	858.15	858.52	858.89
232	859.26	859.63	860.00	860.37	860.74	861.11	861.48	861.85	862.22	862.59
233	862.96	863.33	863.70	864.07	864.44	864.81	865.18	865.55	865.93	866.30
234	866.66	867.04	867.41	867.78	868.15	868.52	868.89	869.26	869.63	870.00
235	870.37	870.74	871.11	871.48	871.85	872.22	872.59	872.96	873.33	873.70
236	874.07	874.44	874.81	875.18	875.55	875.93	876.30	876.66	877.04	877.41
237	877.78	878.15	878.52	878.89	879.26	879.63	880.00	880.37	880.74	881.11
238	881.48	881.85	882.22	882.59	882.96	883.33	883.70	884.07	884.44	884.81
239	885.18	885.55	885.93	886.30	886.66	887.04	887.41	887.78	888.15	888.52
240	888.88	889.26	889.63	890.00	890.37	890.74	891.11	891.48	891.85	892.22
241	892.59	892.96	893.33	893.70	894.07	894.44	894.81	895.18	895.55	895.93
242	896.30	896.66	897.04	897.41	897.78	898.15	898.52	898.88	899.26	899.63
243	900.00	900.37	900.74	901.11	901.48	901.85	902.22	902.59	902.96	903.33
244	903.70	904.07	904.44	904.81	905.18	905.55	905.93	906.30	906.66	907.04
245	907.41	907.78	908.15	908.52	908.88	909.26	909.63	910.00	910.37	910.74
246	911.11	911.48	911.85	912.22	912.59	912.96	913.33	913.70	914.07	914.44
247	914.81	915.18	915.55	915.93	916.30	916.66	917.04	917.41	917.78	918.15
248	918.52	918.88	919.26	919.63	920.00	920.37	920.74	921.11	921.48	921.85
249	922.22	922.59	922.96	923.33	923.70	924.07	924.44	924.81	925.18	925.55
250	925.92	926.30	926.66	927.04	927.41	927.78	928.15	928.52	928.88	929.26
251	929.63	930.00	930.37	930.74	931.11	931.48	931.85	932.22	932.59	932.96
252	933.33	933.70	934.07	934.44	934.81	935.18	935.55	935.92	936.30	936.66
253	937.04	937.41	937.78	938.15	938.52	938.88	939.26	939.63	940.00	940.37
254	940.74	941.11	941.48	941.85	942.22	942.59	942.96	943.33	943.70	944.07
255	944.44	944.81	945.18	945.55	945.92	946.30	946.66	947.04	947.41	947.78
256	948.15	948.52	948.88	949.26	949.63	950.00	950.37	950.74	951.11	951.48
257	951.85	952.22	952.59	952.96	953.33	953.70	954.07	954.44	954.81	955.18
258	955.55	955.92	956.30	956.66	957.04	957.41	957.78	958.15	958.52	958.88
259	959.26	959.63	960.00	960.37	960.74	961.11	961.48	961.85	962.22	962.59
260	962.96	963.33	963.70	964.07	964.44	964.81	965.18	965.55	965.92	966.30
261	966.66	967.04	967.41	967.78	968.15	968.52	968.88	969.26	969.63	970.00
262	970.37	970.74	971.11	971.48	971.85	972.22	972.59	972.96	973.33	973.70
263	974.07	974.44	974.81	975.18	975.55	975.92	976.30	976.66	977.04	977.41
264	977.78	978.15	978.52	978.88	979.26	979.63	980.00	980.37	980.74	981.11
265	981.48	981.85	982.22	982.59	982.96	983.33	983.70	984.07	984.44	984.81
266	985.18	985.55	985.92	986.30	986.66	987.04	987.41	987.78	988.15	988.52
267	988.88	989.26	989.63	990.00	990.37	990.74	991.11	991.48	991.85	992.22
268	992.59	992.96	993.33	993.70	994.07	994.44	994.81	995.18	995.55	995.92
269	996.30	996.66	997.04	997.41	997.78	998.15	998.52	998.88	999.26	999.63
270	1000.00	1000.37	1000.74	1001.11	1001.48	1001.85	1002.22	1002.59	1002.96	1003.33
271	1003.70	1004.07	1004.44	1004.81	1005.18	1005.55	1005.92	1006.30	1006.66	1007.04
272	1007.41	1007.78	1008.15	1008.52	1008.88	1009.26	1009.63	1010.00	1010.37	1010.74
273	1011.11	1011.48	1011.85	1012.22	1012.59	1012.96	1013.33	1013.70	1014.07	1014.44

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
274	1014.81	1015.18	1015.55	1015.92	1016.30	1016.66	1017.04	1017.41	1017.78	1018.15
275	1018.52	1018.88	1019.26	1019.63	1020.00	1020.37	1020.74	1021.11	1021.48	1021.85
276	1022.22	1022.59	1022.96	1023.33	1023.70	1024.07	1024.44	1024.81	1025.18	1025.55
277	1025.92	1026.30	1026.66	1027.04	1027.41	1027.78	1028.15	1028.52	1028.88	1029.26
278	1029.63	1030.00	1030.37	1030.74	1031.11	1031.48	1031.85	1032.22	1032.59	1032.96
279	1033.33	1033.70	1034.07	1034.44	1034.81	1035.18	1035.55	1035.92	1036.30	1036.66
280	1037.04	1037.41	1037.78	1038.15	1038.52	1038.88	1039.26	1039.63	1040.00	1040.37
281	1040.74	1041.11	1041.48	1041.85	1042.22	1042.59	1042.96	1043.33	1043.70	1044.07
282	1044.44	1044.81	1045.18	1045.55	1045.92	1046.30	1046.66	1047.04	1047.41	1047.78
283	1048.15	1048.52	1048.88	1049.26	1049.63	1050.00	1050.37	1050.74	1051.11	1051.48
284	1051.85	1052.22	1052.59	1052.96	1053.33	1053.70	1054.07	1054.44	1054.81	1055.18
285	1055.55	1055.92	1056.30	1056.66	1057.04	1057.41	1057.78	1058.15	1058.52	1058.88
286	1059.26	1059.63	1060.00	1060.37	1060.74	1061.11	1061.48	1061.85	1062.22	1062.59
287	1062.96	1063.33	1063.70	1064.07	1064.44	1064.81	1065.18	1065.55	1065.92	1066.30
288	1066.66	1067.04	1067.41	1067.78	1068.15	1068.52	1068.88	1069.26	1069.63	1070.00
289	1070.37	1070.74	1071.11	1071.48	1071.85	1072.22	1072.59	1072.96	1073.33	1073.70
290	1074.07	1074.44	1074.81	1075.18	1075.55	1075.92	1076.30	1076.66	1077.04	1077.41
291	1077.78	1078.15	1078.52	1078.88	1079.26	1079.63	1080.00	1080.37	1080.74	1081.11
292	1081.48	1081.85	1081.22	1082.59	1082.96	1083.33	1083.70	1084.07	1084.44	1084.81
293	1085.18	1085.55	1085.92	1086.30	1086.66	1087.04	1087.41	1087.78	1088.15	1088.52
294	1088.88	1089.26	1089.63	1090.00	1090.37	1090.74	1091.11	1091.48	1091.85	1092.22
295	1092.59	1092.96	1093.33	1093.70	1094.07	1094.44	1094.81	1095.18	1095.55	1995.92
296	1096.30	1096.66	1097.04	1097.41	1097.78	1098.15	1098.52	1098.88	1099.26	1099.63
297	1100.00	1100.37	1100.74	1101.11	1101.48	1101.85	1102.22	1102.59	1102.96	1103.33
298	1103.70	1104.07	1104.44	1104.81	1105.18	1105.55	1105.92	1106.30	1106.66	1107.04
299	1107.41	1107.78	1108.15	1108.52	1108.88	1109.26	1109.63	1110.00	1110.37	1110.74
300	1111.11	1111.48	1111.85	1112.22	1112.59	1112.96	1113.33	1113.70	1114.07	1114.44
301	1114.82	1115.19	1115.56	1115.93	1116.30	1116.67	1117.04	1117.41	1117.78	1118.15
302	1118.52	1118.89	1119.26	1119.63	1120.00	1120.37	1120.74	1121.11	1121.48	1121.85
303	1122.22	1122.59	1122.96	1123.33	1123.70	1124.07	1124.44	1124.82	1125.19	1125.56
304	1125.93	1126.30	1126.67	1127.04	1127.41	1127.78	1128.15	1128.52	1128.89	1129.26
305	1129.63	1130.00	1130.37	1130.74	1131.11	1131.48	1131.85	1132.22	1132.59	1132.96
306	1133.33	1133.70	1134.07	1134.44	1134.82	1135.19	1135.56	1135.93	1136.30	1137.67
307	1137.04	1137.41	1137.78	1138.15	1138.52	1138.89	1139.26	1139.63	1140.00	1140.37
308	1140.74	1141.11	1141.48	1141.85	1142.22	1142.59	1142.96	1143.33	1143.70	1144.07
309	1144.44	1144.82	1145.19	1145.56	1145.93	1146.30	1146.67	1147.04	1147.41	1147.78
310	1148.15	1148.52	1148.89	1149.26	1149.63	1150.00	1150.37	1150.74	1151.11	1151.48
311	1151.85	1152.22	1152.59	1152.96	1153.33	1153.70	1154.07	1154.44	1154.82	1155.19
312	1155.56	1155.93	1156.30	1156.67	1157.04	1157.41	1157.78	1158.15	1158.52	1158.89
313	1159.26	1159.63	1160.00	1160.37	1160.74	1161.11	1161.48	1161.85	1162.22	1162.59
314	1162.96	1163.33	1163.70	1164.07	1164.44	1164.82	1165.19	1165.56	1165.93	1166.30
315	1166.67	1167.04	1167.41	1167.78	1168.15	1168.52	1168.89	1169.26	1169.63	1170.00
316	1170.37	1170.74	1171.11	1171.48	1171.85	1172.22	1172.59	1172.96	1173.33	1173.70
317	1174.07	1174.44	1174.82	1175.19	1175.56	1175.93	1176.30	1176.67	1177.04	1177.41
318	1177.78	1178.15	1178.52	1178.89	1179.26	1179.63	1180.00	1180.37	1180.74	1181.11
319	1181.48	1181.85	1182.22	1182.59	1182.96	1183.33	1183.70	1184.07	1184.44	1184.82

TABLE XIV—Continued

Area in Ft.	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
320	1185.19	1185.56	1185.93	1186.30	1186.67	1187.04	1187.41	1187.78	1188.15	1188.52
321	1188.89	1189.26	1189.63	1190.00	1190.37	1190.74	1191.11	1191.48	1191.85	1192.22
322	1192.59	1192.96	1193.33	1193.70	1194.07	1194.44	1194.82	1195.19	1195.56	1195.93
323	1196.30	1196.67	1197.04	1197.41	1197.78	1198.15	1198.52	1198.89	1199.26	1199.63
324	1200.00	1200.37	1200.74	1201.11	1201.48	1201.85	1202.22	1202.59	1202.96	1203.33
325	1203.70	1204.07	1204.44	1204.82	1205.19	1205.56	1205.93	1206.30	1206.67	1207.04
326	1207.41	1207.78	1208.15	1208.52	1208.89	1209.26	1209.63	1210.00	1210.37	1201.74
327	1211.11	1211.48	1211.85	1212.22	1212.59	1212.96	1213.33	1213.70	1214.07	1214.44
328	1214.82	1215.19	1215.56	1215.93	1216.30	1216.67	1217.04	1217.41	1217.78	1218.15
329	1218.52	1218.89	1219.26	1219.63	1220.00	1220.37	1220.74	1221.11	1221.48	1221.86
330	1222.22	1222.59	1222.96	1223.33	1223.70	1224.07	1224.44	1224.81	1225.18	1225.55
331	1225.93	1226.30	1226.67	1227.04	1227.41	1227.78	1228.15	1228.52	1228.89	1229.26
332	1229.63	1230.00	1230.37	1230.74	1231.11	1231.48	1231.85	1232.22	1232.59	1232.96
333	1233.33	1233.70	1234.07	1234.44	1234.82	1235.19	1235.56	1235.93	1236.30	1236.67
334	1237.04	1237.41	1237.78	1238.15	1238.52	1238.89	1239.26	1239.63	1240.00	1240.37
335	1240.74	1241.11	1241.48	1241.85	1242.22	1242.59	1242.96	1243.33	1243.70	1244.07
366	1244.44	1244.82	1245.19	1245.56	1245.93	1246.30	1246.67	1247.04	1247.41	1247.78
337	1248.15	1248.52	1248.89	1249.26	1249.63	1250.00	1250.37	1250.74	1251.11	1251.48
338	1251.85	1252.22	1252.59	1252.96	1253.33	1253.70	1254.07	1254.44	1254.82	1255.19
339	1255.56	1255.93	1256.30	1256.67	1257.04	1257.41	1257.73	1258.15	1258.52	1258.89
340	1259.26	1259.63	1260.00	1260.37	1260.74	1261.11	1261.48	1261.85	1262.22	1262.59
341	1262.96	1263.33	1263.70	1264.07	1264.44	1264.82	1265.19	1265.56	1265.93	1266.30
342	1266.67	1267.04	1267.41	1267.78	1268.15	1268.52	1268.89	1269.26	1269.63	1270.00
343	1270.37	1270.74	1271.11	1271.48	1271.85	1272.22	1272.59	1272.96	1273.33	1273.70
344	1274.07	1274.44	1274.82	1275.19	1275.56	1275.93	1276.30	1276.67	1277.04	1277.41
345	1277.78	1278.15	1278.52	1278.89	1279.26	1279.63	1280.00	1280.37	1280.74	1281.11
346	1281.48	1281.85	1282.22	1282.59	1282.96	1283.33	1283.70	1284.07	1284.44	1284.82
347	1285.19	1285.56	1285.93	1286.30	1286.67	1287.04	1287.41	1287.78	1288.15	1288.52
348	1288.89	1289.26	1289.63	1290.00	1290.37	1290.74	1291.11	1291.48	1291.85	1292.22
349	1292.59	1292.96	1293.33	1293.70	1294.07	1294.44	1294.82	1295.19	1295.56	1295.93
350	1296.30	1296.67	1297.04	1297.41	1297.78	1298.15	1298.52	1298.89	1299.26	1299.63
351	1300.00	1300.37	1300.74	1301.11	1301.48	1301.85	1302.22	1302.59	1302.96	1303.33
352	1303.70	1304.07	1304.44	1304.82	1305.19	1305.56	1305.93	1306.30	1306.67	1307.04
353	1307.41	1307.78	1308.15	1308.52	1308.89	1309.26	1309.63	1310.00	1310.37	1310.74
354	1311.11	1311.48	1311.85	1312.22	1312.59	1312.96	1313.33	1313.70	1314.07	1314.44
355	1314.82	1315.19	1315.56	1315.93	1316.30	1316.67	1317.04	1317.41	1317.78	1318.15
356	1318.52	1318.89	1319.26	1319.63	1320.00	1320.37	1320.74	1321.11	1321.48	1321.86
357	1322.22	1322.59	1322.96	1323.33	1323.70	1324.07	1324.44	1324.81	1325.18	1325.55
358	1325.93	1326.30	1326.67	1327.04	1327.41	1327.78	1328.15	1328.52	1328.89	1329.26
359	1329.63	1330.00	1330.37	1330.74	1331.11	1331.48	1331.85	1332.22	1332.59	1332.96

be only such as is unavoidable. When the necessary preparation has been made, the track must be crossed as quickly as possible by some method that will insure safety to all concerned.

Right of way must be secured from the landowners for each public or district ditch. This should give the proper authorities the right to enter upon such land to construct and maintain the ditch, but does not prevent the owners from using the land which is not occupied by the ditch. The width of the strip of land required for the purpose varies with the size of the ditch, but for a minimum dredge ditch should be 80 feet, 120 feet being commonly used for ditches not wider than 40 feet. This strip of land must be secured before the excavation begins, the cost becoming a charge against the districts in the form of damages. Such charges are usually computed at a price per acre unless the course of the ditch follows a natural watercourse, in which case the right of way is secured without cost. **Table XV** shows at a glance the number of acres contained in right-of-way strips of different widths, and will be found convenient in making estimates of that kind.

Where the ditch is to be made through a wooded district, the timber on the entire right of way should be cut down and removed, the brush and slashings being burned upon the ground. Stumps twelve or more inches in diameter that are found in the path of the ditch are shattered by dynamite in such a manner that they can be lifted in sections by the dipper of the dredge. To do this effectively the stick of dynamite should be exploded at the base of the stump underneath the surface of the ground, better results being obtained if water covers the surface. The smaller stumps can be removed by the dipper after the earth about the roots has been partially excavated.

TABLE XV

Acres Required for Right of Way for Ditches of Different Widths

Width Ft.	Acres per 100 Ft.	Acres per Mile	Width Ft.	Acres per 100 Ft.	Acres per Mile
1	.002	.121	41	.094	4.97
2	.005	.242	¼	.094	5.
3	.007	.364	42	.096	5.09
4	.009	.485	43	.099	5.21
5	.011	.606	44	.101	5.33
6	.014	.727	45	.103	5.45
7	.016	.848	46	.106	5.58
8	.018	.970	47	.108	5.70
¼	.019	1.	48	.110	5.82
9	.021	1.09	49	.112	5.94
10	.023	1.21	½	.114	6.
11	.025	1.33	50	.115	6.06
12	.028	1.46	51	.117	6.18
13	.030	1.58	52	.119	6.30
14	.032	1.70	53	.122	6.42
15	.034	1.82	54	.124	6.55
16	.037	1.94	55	.126	6.67
½	.038	2.	56	.129	6.79
17	.039	2.06	57	.131	6.91
18	.041	2.18	¾	.133	7.
19	0.44	2.30	58	.133	7.03
20	.046	2.42	59	.135	7.15
21	.048	2.55	60	.138	7.27
22	.051	2.67	61	.140	7.39
23	.053	2.79	62	.142	7.52
24	.055	2.91	63	.145	7.64
¾	.057	3.	64	.147	7.76
25	.057	3.03	65	.149	7.88
26	.060	3.15	66	.151	8.
27	.062	3.27	67	.154	8.12
28	.064	3.39	68	.156	8.24
29	.067	3.52	69	.158	8.36
30	.069	3.64	70	.161	8.48
31	.071	3.76	71	.163	8.61
32	.073	3.88	72	.165	8.73
33	.076	4.	73	.168	8.85
34	.078	4.12	74	.170	8.97
35	.080	4.24	¼	.170	9.
36	.083	4.36	75	.172	9.09
37	.085	4.48	76	.174	9.21
38	.087	4.61	77	.177	9.33
39	.090	4.73	78	.179	9.45
40	.092	4.85	79	.181	9.58

TABLE XV—Continued

Width Ft.	Acres per 100 Ft.	Acres per Mile	Width Ft.	Acres per 100 Ft.	Acres per Mile
80	.184	9.70	¾	.209	11.
81	.186	9.82	91	.209	11.0
82	.188	9.94	92	.211	11.2
½	.189	10.	93	.213	11.3
83	.190	10.1	94	.216	11.4
84	.193	10.2	95	.218	11.5
85	.195	10.3	96	.220	11.6
86	.197	10.4	97	.223	11.8
87	.200	10.5	98	.225	11.9
88	.202	10.7	99	.227	12.
89	.204	10.8	100	.230	12.1
90	.207	10.9			

Bridges. Another point that should not be overlooked in the prosecution of this work is the location of new bridges for farm use. These are not a part of the ditch construction, but should be located in advance in order that the waste banks can be so deposited as to leave a passageway to the bridge when it is constructed. Farm bridges are usually of the wooden truss pattern, but the present tendency is toward steel structures set upon concrete abutments, on account of the heavy machinery and traction engines which both farm and highway bridges are required to support. In order to safely do this they should be designed for a moving load of 100 pounds per square foot, with a factor of safety of 4.

Water Inlets. Openings should be required in the banks where tributary streams or ditches enter, but no overfall of water should be permitted at such entrances, the connections being made as suggested in **Chap. XV.** Water inlets should be located in advance of the construction of the ditch, and where practicable should be in the form of large pipes so located and laid that they will discharge near the bottom of the ditch. They

should be placed in position so that the waste bank can be continuous and the labor of digging through it after the ditch has been completed be avoided.

Where the ditch crosses a natural watercourse, as is done in straightening a crooked stream, the natural channel should be closed on the lower side only. It is then used to receive drainage from the lands tributary to it, and discharges into the new channel. In case, however, the old channel is small the banks may be made solid on both sides and water be admitted through them by suitable pipes and sluices.

Roadway on Bank. It is frequently desirable to make a highway, public or otherwise, on one of the banks. This, in fact, is a valuable feature of the reclamation of large marshes. If the excavated material is wet, it can be spread quite evenly by the operator of the dredge, if care is taken. This, however, slightly increases the expense, and if such work is to be required it should be named in the specifications. Stakes should also be set by which the top of the road is to be graded. The guides should be posts well set in the ground at intervals of 300 feet, and cut off at the height required for the road. They can then be used at any time during the excavation as a guide in distributing the waste banks and, later, in surfacing the road. If sandy material is found in some parts of the ditch, as is sometimes the case, it can be utilized by depositing it as a top layer on the road. But little shrinkage takes place in such a bank, 3% being the limit if the earth is wet when deposited, and if logs, brush and other foreign material are excluded.

Construction. The duties of the engineer in connection with construction consist in setting such stakes as the contractor may need for his guidance in excavating the ditch, inspecting the work to ascertain if the speci-

fications are being followed, and making estimates of completed work as required by the terms of the contract. Some permanent grade-stakes should be set in advance of the workmen along the berm at regular intervals, upon which is marked the depth of the channel opposite the points. By the use of cross-bars set above the hubs for sighting, both contractor and engineer can, at any time, test the bottom of the ditch as to its depth and grade.

Sides of Ditch. Smoothness of the sides of the ditch and the waste banks is not so important as regularity and symmetry of shape. The action of the water and weather will reduce the banks to the required smoothness provided there are no deep cavities or out-jutting earth left by the dipper. It should be observed in this connection that rough and ill-shaped ditches are often made by contractors on the plea that it is impracticable to make them otherwise with the machine they are using. This feature of the work, however, depends largely upon the care and skill exercised by the operator, but any special care of this kind requires more time and hence adds somewhat to the expense. Floating machines do their excavating under water and in a general way keep the grade of the ditch by the length of the dipper handle beneath the surface of the water. The depth is checked from time to time by measurements from the grade-stakes which have been set along the berm by the engineer.

Dry-land machines, that is those that operate from the surface of the ground, can be so manipulated as to make almost any desired side slope, and special slopes should be specified and insisted upon in land where the stability of the ditches requires their use. Flat slopes can be easily made where horses and traction engines are used as power, and the various forms of slip

scrapers and elevator graders are employed to do the work.

The examination of the completed ditch should be made with the level and measuring tape, and a report be prepared setting forth the condition of the ditch and its conformity to the plans and specifications.

Ditching Machines. Drainage ditches should be planned so that they can be excavated by machines. There are a number of types of these, each of which is adapted to its own class of work, the limitations and capabilities of which should be known to the engineer.

The floating dipper-dredge is well-suited to the construction of large ditches where there is water in sufficient volume to float the barge which carries the machinery. Ordinarily, the smallest ditch that can be made with it is 15 feet wide on the bottom, though this depends upon the depth of ditch and upon the depth of water in it at the time of excavation. The dippers ordinarily used range from 3/4 yard to 2 1/2 yards. They are adapted to the excavation of ditches of 15 to 50 feet bottom width, and are now made of such strength that ditches through heavily wooded country can be excavated expeditiously and at moderate price. In such work, dynamite is used to shatter the large stumps, after which they are lifted out by the dipper and cast one side. The dredge is operated most cheaply downstream since the water follows and floats the barge. By making dams, however, to retain the water in sufficient quantity to float the dredge, it can be operated up grade.

The combined floating and walking dipper-dredge is adapted to ditches as small as 15 feet bottom width, and is equipped with a walking device by means of which it can move itself across a level country at the rate of one mile a day.

There is also **the traction dipper-dredge,** which moves over the surface on caterpillar or rough-belted wheels. This goes astride the ditch up grade, and with a ¾ yard dipper completes as small a ditch as may be desired.

The drag-excavator is another type which operates from the surface of the ground and takes its name from the type of bucket employed. The bucket is in the form of a slip-scraper and is filled in the same manner, then raised by a wire cable which passes over the end of a boom and thence to the winding drum operated by the engine. The bucket is then swung to one side and tripped. The machine may move on rollers placed on a track of timbers ahead of the ditch, or it may move on one side of the ditch. The buckets are made for this work as large as 2½ yards capacity. By means of a long boom it will deposit the earth at a greater distance from the ditch than a dipper-machine, and for that reason is adapted to the construction of levees and embankments, and can be used for large or small ditches wherever the ground is sufficiently stable to support the machine.

Two other types of buckets known as **the orange-peel** and **the clam-shell** are fitted for excavating and moving material which is sufficiently soft to permit buckets of that class to be filled. The orange-peel is particularly useful in building levees.

The ladder type of dredge works well in the excavation of loose and sandy earth, particularly where large ditches are required.

The well-known **hydraulic dredge** is especially suited to large projects and to special work.

These are the general types of machines which are in common and successful use for excavating large open ditches. The perfection of these several types has

made it possible for the engineer to carry out reclamation projects of great magnitude with thoroughness and reasonable dispatch. Compared with the implements and methods which were available to engineers fifty years ago, progress in this direction has been remarkable.

Specifications. A part of the engineer's service in connection with surveys and plans which he makes is to draw specifications for constructing the works. The contractor should know not only the character of the work upon which he tenders a bid, but the regulations under which he must perform the work. The engineer should be familiar with the contingents incident to construction in order to frame the specifications so that the work will be thoroughly and well done, and yet not entail needless hardship upon the contractor. While the stipulations which should be embodied in specifications must be varied to meet the needs of different classes of work, the following memorandum of points that should be kept in view will be helpful.

Relation of Engineer and Contractor. It is commonly required that the work be done under the direction of the engineer, and according to the maps, plans and profiles which are made a part of the specifications. The contractor shall use methods and appliances which in the judgment of the engineer will enable him to complete the work within the time and in the manner specified.

Subletting of Contract. Work shall not be sublet without the written consent of the engineer, and such action shall not relieve the contractor from his obligations for the satisfactory performance of the work.

Change of Plan. It sometimes becomes advisable to change the plans after the contract has been let. Where such changes involve a difference of cost to the con-

tractor they shall be agreed to by both parties to the contract, and the price of work required by the change of plans shall be based upon the price named in the contract. No claim should be allowed for extra work except upon the written order of the engineer.

Risks and Delays. It is usually required that the contractor shall make no charge for delay on account of legal difficulties which may occur, or for the failure of any other contractor to do his work, but he shall be entitled to an extension of time in which to complete the contract. He shall assume all risks due to the weather or other unforeseen occurrences.

Defective Work and Damages. In case defective work is done the engineer may require the contractor to make it good, or, if in the engineer's judgment it is undesirable for any reason to do so, he may make such deductions from the price as he deems reasonable. The contractor should be held responsible for unnecessary damages to property through which the ditch is constructed.

Clearing Right of Way. In wooded country the price of excavation may be made to include clearing right of way for the ditch, or an additional price per lineal one-quarter mile, or other unit, may be allowed. In either case it should be stipulated who is to have the timber. Removing and replacing highway bridges and fences should be provided for. Usually this is required of the contractor.

Berm and Side Slope of Ditches. A berm of not less than eight feet should be specified for ordinary work, and the side slopes designated should be such as will be required in the finished ditch. These will be governed by the kind of land through which the ditch is to be made. Openings in the waste banks should be made for the entrance of tributary ditches and streams.

Inspection and Partial Payments. It is customary for the contractor to receive monthly payments of 75% or 80% of completed work upon the estimate of the engineer, the balance to be paid upon the completion of the contract.

Survey Stakes. The stakes set by the engineer for the guidance of the contractor are an essential part of the specifications and must be followed, and as far as possible preserved, during the execution of the work.

In general, it may be said that the more complete the plans have been made the more simple the specifications may be. A clause in the contract requiring the work to be done according to the plans will then eliminate many questions which would otherwise require adjustment as the work proceeds.

Camping Outfits. Where an extended survey is to be made, either preliminary or location, it will be best to use a camp, moving it from point to point so that the men can be kept within convenient distance of the work as it proceeds. The following outfit will serve for a party of eight men, including a cook and teamster.

3 14′ x 14′ tents with 4′ walls of 12 oz. army duck, with fly, poles and pins for each.

1 Steel box cooking range.

1 Doz. folding canvas cots.

1 Doz. folding stools.

2 Boxes of convenient size, one for provisions and one for table-ware.

1 Set light cooking utensils, three lanterns, supply of fly-netting and kitchen towels.

1 Set enameled or granite table-ware.

Boards for a dining-table and for table seats.

A small tent for office work can be added if desired. Each man furnishes his own bedding and towels. The entire outfit should be as light as will be consistent with

durability and strength, for the reason that the camp must be moved frequently, and the delay and labor incident to moving and setting up a heavy outfit, involves a considerable additional expense. If desirable, by a little crowding, two tents can be made to accommodate a party of this size.

CHAPTER XV

PROBLEMS IN OPEN-DITCH WORK

Curvature of Ditches. The proper curve to give ditches when they are deflected from a straight line is a matter which merits careful attention. It is desirable that the adjustment of curve to velocity of flow be such that the banks will not require artificial protection. The relation of bank erosion to curvature of the ditch and the velocity of flow is intricate, owing to the great difference in the stability of earth when subjected to the action of water.

Circular curves are described by the number of degrees of arc which a chord of 100 feet subtends. The degree of a curve is determined by the central angle which is subtended by a chord of 100 feet. The following is a table of curves and their corresponding radii which may be used as a basis in constructing ditches with limitation as hereafter described.

TABLE XVI

Curves and Radii

Degree	Radius in Ft.	Degree	Radius in Ft.
7	819	14	410
8	717	15	383
9	637	16	359
10	574	17	338
11	522	18	320
12	478	19	303
13	442	20	288

While circular curves may be used to describe approximately the curvature that should be given, the true form should not be geometrical, but rather what may be termed natural, or such as is used in laying out artificial streams and roads in parks, in which geometrical lines are ignored. The difference between the two is shown in **Fig. 47**, which is a 12-degree curve (radius 478 feet), so varied as to subject the bank against which the

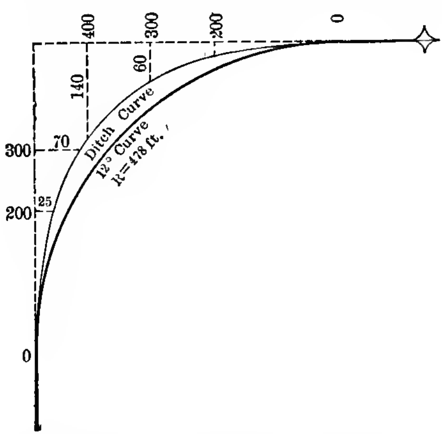

FIG. 47.—PROPER CURVE FOR OPEN DITCHES

stream strikes, when first deflected, to the least possible erosion. The reason for this is well illustrated by **Fig. 48**, in which the stream is represented as being divided into filaments, each having a velocity imparted to it by the flow, and striking the opposite bank as an individual force. According to the well-known law of physics, the angles of incidence and reflection are equal when a force meets a resisting plane. Hence in the case under consideration, the reflected force is thrown against the other forces or filaments toward the interior

of the stream and assists in breaking the force and deflecting the current. The section of curve first struck would receive the greatest force, and be subject to greater erosion if the curve were a segment of a circle. For this reason the up-stream part of the curve should be deflected from the tangent by using a curve of greater radius than the remainder of the curve, in order that all parts may be subject to uniform erosion.

When the points of tangency have been fixed upon, the curve may be "run in by the eye" better than by

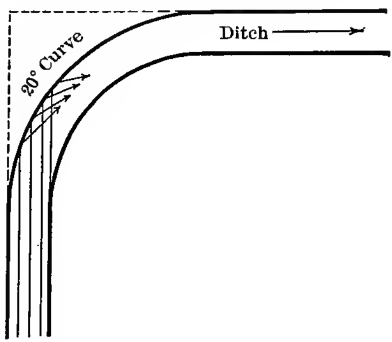

FIG. 48.—ACTION OF CURRENT ON DITCH BANKS AT CURVES.

an instrument, and the center line located by measurements from the tangents in the manner shown in Fig. 47.

How short a curve may be used in large ditches such as are constructed for drainage districts, without endangering the stability of the banks at the curve, is a question that can not be answered with mathematical certainty for the reasons previously stated. Deductions from close observations of both natural and artificial streams which flow through alluvial soils are the only guides to the work. From such observations the following empirical rules may be deduced:

For ditches with minimum bottom width of 6 feet and maximum grade of 2 feet per mile, use 20-degree curve = radius of 288 feet. For ditches with bottom width 6 feet to 20 feet and grade of 3 feet to 6 feet per mile, use 12-degree curve = 478 feet.

For larger ditches and greater fall, or for the above-named ditches with a greater fall than indicated, curves ranging between 6 degrees and 12 degrees may be used, with such latitude as conditions of earth and fall may suggest to the careful designer.

Erosion. Injury to ditches by erosion occurs in two ways: by direct wearing away of the banks through the action of the water, which removes the particles of earth and carries them by suspension down-stream; and by the action of water upon a stratum of earth in the bank more susceptible than the rest, thus undermining a portion of the bank, causing large masses to fall into the channel. The latter is the more destructive of the two and the more difficult to prevent.

The eroding power of a stream increases directly as the square of the velocity; that is, the relative eroding power of two streams having velocities of 2 feet and 3 feet per second, respectively, is as 4 to 9. Since velocity varies directly as the square root of the rate of fall of the channel, the eroding power varies as the fall of the stream; that is, it is twice as great on a stream with a fall of 4 feet per mile as on one with a grade of 2 feet per mile. This, of course, refers only to the wearing effect against a bank, but this law points out certain methods of diminishing erosion and the consequent caving of the banks of a ditch or stream.

Erosion may be lessened by widening the channel so that the depth of flow will be diminished and the consequent velocity reduced; by making the grade of the bottom as even as practicable; and by removing

obstructions from the center portion of the channel so that the velocity will be as uniform as it is possible to make it. These methods are applicable to general conditions, and should be regarded in designing ditches. Sometimes the side slopes may be made more flat, which will have the effect of reducing the velocity of flow along the sides of the channel. In case of large streams, wing dams or dikes can be used to deflect the current away from the banks and cause it to follow the center of the channel. Much trouble is experienced, in alluvial soils and others which erode easily, at points where lateral ditches enter the mains, particularly if the branch en-

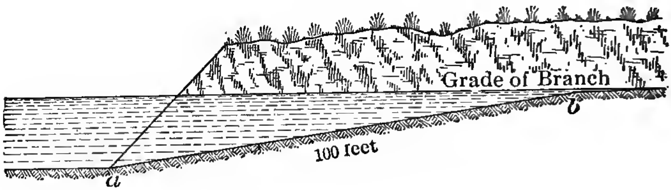

FIG. 49.—PROPER JUNCTION OF SHALLOW AND DEEP DITCHES.

ters at a higher level by an overfall. The effect is to form a bar of silt just below the point where the branch enters, and to cause the branch ditch to erode badly for some distance up-stream. Much of this difficulty can be avoided by having the lateral ditches cut down to such a grade that the point of discharge will be at the bottom of the main. Provision should be made at all points where water discharges into open ditches to eliminate all overfall or drop, unless such entrances are protected by structures of timber or concrete. In **Fig. 49** the line **a b** indicates how the grade of a shallow ditch should be changed to avoid the washing away of earth and consequent filling of the deeper ditch into which it

empties that will occur if the branch is permitted to discharge on its regular grade by overfall.

Decrease of Flow Due to Obstructions. The differences in flow and consequent discharge between channels in good physical condition and those in bad condition are much greater than is usually assumed. Ditches and watercourses often become obstructed by bars of silt, accumulations of brush, logs or other débris, and by jutting banks bearing clumps of bushes and trees, all of which detract materially from their carrying capacity. As before stated, the measure of these differences is represented in Kutter's formula by the factor **n**, to which values corresponding to the roughness of the channel are assigned varying from .02 to .05 (See **Value of n, Chap. XII**). The effect of these variations upon the flow of a ditch 20 feet wide and 7 feet deep is that when $n = .0225$, the ditch will carry 31% more than when $n = .03$, and 50% more than when $n = .035$. This emphasizes the importance of freeing a drainage channel from all obstructions possible, and of maintaining it in good condition. The possible betterment of the physical conditions of an existing channel should receive first consideration where the general improvement of the drainage of a country is contemplated. Not infrequently its effective capacity can be increased one-third by removing trees, brush and other obstructions which retard the flow and diminish the uniform sectional area of the channel. This is particularly true of streams 20 to 60 feet in width. Such improvements can be made at a cost far less than any other giving equal results.

Cutting off Bends in Crooked Channels. A crooked channel may be greatly increased in carrying capacity by cutting across the bends in such a way that the water will flow in a fairly straight line down the valley, provided the size of the channel throughout is properly ad-

justed to the new conditions. The fall through a given valley being a fixed amount, it follows that the shortest line will have the greatest percent of grade and resulting velocity. If the channel through which the water flows is shortened to one-half its original length, the rate of fall will be doubled; since the velocity of flow in the same channel varies as the square root of the head or fall, the ratio in the above assumption would be the $\sqrt{1}$ to $\sqrt{2}$ or 1 to 1.41. If the channel is shortened to one-fourth

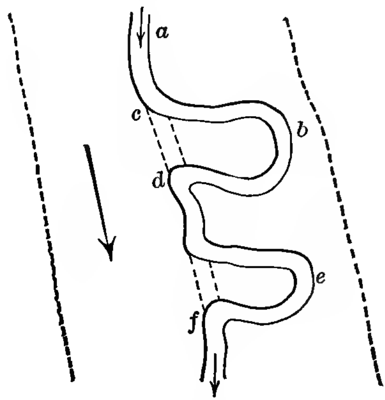

FIG. 50.—CUTTING OFF BENDS IN CROOKED CHANNELS.

its original length the velocity will be doubled, the size and other conditions of the channel remaining the same.

This method of improvement should be consistent throughout the valley, otherwise the relief of one part of the stream may result in the congestion of the water and consequent overflow of lands in another. Let **a b e f** in **Fig. 50** represent a crooked channel which by reason of its insufficient capacity causes overflow. If we eliminate the bend **b**, by making the cutoff **cd**, the new channel will be only one-fourth as long as the old one,

and the velocity of flow through it will be double that through the old course. Unless the channel **de** has sufficient capacity to accommodate the increased flow, which in some instances is the case, it will be overcharged and overflow conditions will be increased along that part. For this reason it will be necessary to continue the straightening process down the stream and also possibly to improve the original channel in order that the benefits of increased drainage facilities may be uniform along its course. The combined flow of the cutoff and bend may be utilized, but it should be understood that the channel at the junction of the two, as at **d**, should have a capacity sufficient to receive the combined flow.

Waterway between Levees. The improvement of streams for the protection of overflowed bottom-lands often requires the construction of levees on each side of the channel, because the enlargement of the channel to sufficient dimensions to carry the entire quantity would be either impracticable or too expensive. The problem to be solved in such cases is to determine the height of the levees and the distance apart that they should be placed in order to meet the requirements.

The volume of water which must be provided for should first be estimated. If there is some point on the stream where the volume has been gaged with approximate accuracy, the result will assist in estimating the volume, in case the flow should be confined between levees, but even such measurements may easily mislead the engineer for the reason that the channel may overflow at points and fill up portions of the valley as it would a reservoir, so that the maximum flow does not represent that which would take place in a well-prepared channel.

The better method of arriving at the amount is to estimate the runoff from the entire area by every means available, observing particularly the manner in which

the water comes into the main channel, that is whether it is brought by a few large tributaries from a considerable distance, or by small short streams which discharge their contents quickly into the center of the valley. Having decided upon the number of second-feet that should be carried, estimate the capacity of the existing channel and then, by trial, compute the capacity of a waterway between levees with assumed heights and at different distances apart until a channel has been found that will carry the required amount.

In computing the capacity, the channel should be treated in three parts: the central or river-channel part, and the two sides, where the water will be comparatively shallow and the bottom more obstructed than that of the main channel.

Let **Fig. 51** represent a stream which it is proposed to control by levees on each side. Using Kutter's formula, we first compute the discharge of the central channel, **e b c f.** The wet perimeter is **a b c d**, because **e a** and **f d** are water-surfaces and present little or no frictional resistance. The area of the waterway below

FIG. 51.—WATERWAY BETWEEN LEVEES.

and above the level of the land, that is, **e b c f**, divided by the length of **a b c d** = **r.** The value of **n** will be perhaps **.025**. Having the slope of the valley, the discharge can be computed by substituting the proper quantities. The portion of the waterway on each side of the central channel may be regarded as two distinct parts, as the distance from the main channel to the levees is not always equal. The wet perimeter of **f d h g**, in the figure,

is d h g since f d being water-surface may be disregarded. The value of r is then the area of f d h g divided by the length of d h g. The value of n for this part of the channel may be .035, or more, depending on the surface and obstructions in the side channel. The sum of the discharges of the central and two side channels will be the approximate total discharge of the assumed waterway. The levees should be built three feet higher than the estimated height of the water in the channel, and even a larger margin should be allowed if the volume of flow cannot be estimated closely.

Effect of Weirs and Dams. The effect of a dam with a free outlet below it is to permanently raise the water-surface from the location of the dam up-stream to a point where the rise in the grade of the channel is equal to the height of the dam, plus the head or rise which will be required to overcome the frictional resistance to flow offered by the dam. The rise occasioned by the dam is less if it is located where the channel is broad, as that will diminish the height of the crest at the dam. The effect of removing the dam is to lower the plane of the stream the amount it was raised by the obstruction, and to that extent benefiting the drainage conditions of the land adjoining the pond which was caused by the dam. By reason of the backwater curve which exists on the surface of the water above obstructions of this class, the surface is sometimes 6 inches higher one-half mile above the dam than at its crest. As far as it relates to drainage, the dam is a local obstruction which does not affect the flow of the stream above the upper point of rise occasioned by it, where the velocity is governed by the gradient and the physical conditions of the channel.

Raised Outlets. It may be necessary to discharge the drainage of a large tract through a main ditch into

a shallow stream or a swamp from which the water distributes itself and slowly disappears. The ditch has been made 7 or 8 feet deep, but the water must be discharged into a channel which may be only 2 or 3 feet deep. The question arises whether under such circumstances the ditch should be graded so as to deliver the water at the level of the shallow outlet, or whether it should be extended its full depth and then depend upon the water rising to the higher level for an outlet. The latter method is the proper one as will be seen from the following explanation:

Let **hk**, **Fig. 52**, be the bottom of a ditch 8 feet deep, carrying water 4 feet deep, the surface of which would be at **l m** if the flow were unobstructed. Let **l g** be the

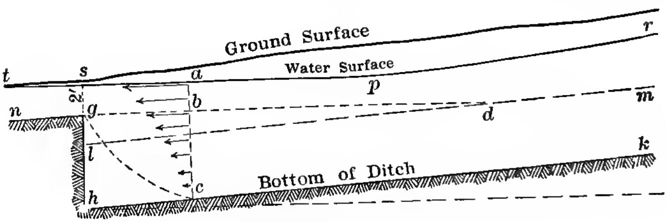

FIG. 52.—RAISED OUTLET.

rise which the water must make in order to flow through a shallow channel two feet deep whose bottom is **g n**.

The line **g d** represents the level above which the water must rise to flow away, the point **d**, the hydrostatic limit, and **a b**, the depth of water which may flow through the outlet **g s**. The movement of water over **g n** is due to the relief which is afforded at **g**, and also to the "piling up" of water at **p** which extends up-stream for a distance, forming what is called the backwater curve. The entire column of water **a c** has a mean velocity due to a head which is the difference in level

between **t** and **r**. If then the width and slope of the channel at **g n** be sufficient to take the discharge from the large channel flowing under a head due to surface slope, as before explained, the entire volume of water will flow away at a velocity due to that head.

As the water meets the obstruction **h g** the part below the curve **g c** will have no velocity, while the velocity of the column of water from the bottom to the surface, represented by the line **c a**, will increase in some such manner as is shown by the arrows. The form of the backwater curve, **p r**, varies with the slope of the stream and the volume of water it carries. The limit of length, and also the rise, in the backwater curve is small, as for example, in a stream of light grade, the former is two miles, in which distance there may be a rise of six inches.

The important point to observe in constructing an outlet to a ditch under these conditions is to make it sufficiently wide to carry the estimated volume of flow. There will be a risk from sedimentation, but this will be diminished by making the outlet large in the manner suggested. It is needless to mention that the land affected by the backwater will receive little benefit.

CHAPTER XVI

DRAINAGE DISTRICTS

A DRAINAGE district is an organization of the owners of land formed for the purpose of constructing and maintaining adequate drainage outlets whose cost shall be shared in proportion to the benefits derived.

The kinds of land properly subject to such organization are swamps or wet lands, wholly or partially unreclaimed; farm lands which have insufficient outlets; lands in river and creek valleys which are subject to overflow; and coast and tidal lands subject to inundation by the sea. The ultimate object of draining such lands is to fit them for the profitable production of crops, and whatever improvements may be demanded by an intelligent and cultured people. Such work consists of two parts; the public drainage, which is accomplished by the cooperation of all the owners in the construction of necessary outlets whose cost is assessed to the several parties in proportion as they are benefited, and the private, or individual, work which is required on each farm and for which the owner himself pays.

Three areas are considered in the development of plans for the construction of public ditches; first, the entire watershed tributary to and including the land in the district; second, the district itself which is benefited and controlled by the organization; third, the individual farms of which the district is composed and for which the organization has been perfected.

The work which is required may be the enlarging or straightening of a watercourse by which a number of

landowners will be mutually benefited; the construction of an extensive system of outlet ditches; or the building of levees and sluices, and the installation of pumping plants; but the method of organization and the successive steps in the promotion of the project are the same.

Drainage Laws. The formation and management of districts is provided for in most States by laws which direct in detail the steps which should be taken and give methods of procedure which must be closely followed in order to make the proceeding valid. These vary in the several States in many particulars, but the essential features of a drainage law are: first, the right given to property owners under certain prescribed conditions to petition the proper authority for the construction of drains which will be of public benefit; second, provision for making and collecting assessments to defray the cost of the work, and also for the appraisement and payment of damages to property incident to such construction; third, the establishment of the perpetual right of landowners included in the district to use the ditches or drains which are constructed; fourth, authority under proper legal regulations to incur debt and sell bonds for obtaining money with which to perform the public part of the work.

Survey and Report. The law places surveys under the direction of a board or an officer of the law, with authority to order them, and to receive and pass upon the report of the engineer. Upon his appointment the engineer should make a preliminary examination of the territory covered by the petition, previously filed with the proper authority, and outline to the board the kind of survey which he recommends, together with its approximate cost. Such boards usually refer these matters to the judgment of the engineer, who should ex-

ercise great discretion, so that while no unnecessary work will be done and costs incurred, sufficient data will be secured for the development of the necessary plan. Suggestions in other chapters regarding preliminary location of surveys should be followed in this work.

The report should be accompanied by a carefully prepared map showing the ownership and acreage of each tract of land in the district, together with such elevations or contour lines and topographical symbols as will show the drainage needs of each, the location of railroads, inter-urban lines and public highways crossing the district, and the proposed location of the ditches. The report should state the manner in which the latter will benefit the lands, and the general advantages which will accrue to the district as a whole.

Estimate of Costs. Drainage laws usually specify that the petition should not be granted unless it is shown that the benefits which will accrue from the proposed work will be greater than its cost, hence before assessments can be made or active operations commenced the engineer must prepare a detailed estimate of the cost of the contemplated work, covering the following points: (a) the construction of the drains, which includes excavation, such tile as may be required, the construction of any surface-inlets that may be needed, and the removal and replacing of highway bridges if the law requires this done by the district; (b) damages, which include the cost of right of way for drains or ditches, the construction of necessary bridges on railroads, highways, or farm lands, and amounts paid by reason of injury or inconvenience to private fields, or to roads and railroads; (c) the cost of engineering superintendence, and fees of commissioners; (d) legal expenses arising from necessary attorney's fees and those due to suits which may be carried to court.

Appraisal of Damages. The law usually requires that damages shall be awarded by a commission appointed for that purpose, some of the States specifying that this board and the one to assess benefits shall be entirely distinct in their personnel and deliberations. In any case the consideration of damages is conducted regardless of benefits, the two not being allowed to offset each other, but the damages are awarded and paid and the amount added to the total cost without reference to the assessment of benefits.

When the outlet drain is an open ditch, the chief damages are the value of the land for right of way. Opinions and practice differ as to the basis of valuation for such area, some holding that its selling price at the time of appraisal should constitute the amount of damage awarded, on the ground that giving the land for the ditch is the same as selling it. Others consider that if the land occupied by the ditch would be tillable when drained, its value under the improved conditions should be the basis of award, because the owner loses land that would have been rendered valuable if the ditch had chanced to run on his neighbor's side of the fence. These claim that giving the land for the ditch is not comparable to voluntary sale of it for the reason that in the majority of cases the owner would prefer to pay the cost of improvement and retain the land than be obliged to give it up. If the course of the ditch is a natural waterway and would not be tillable land under improved conditions, then only the value of such tillable land as is occupied by berm and waste banks or in straightening the course of the natural channel should constitute the damages.

Minor damages may be awarded because of extra time and labor required annually owing to inconvenient division of fields by the ditch, or because it runs through

farm yards, or too close to buildings, or through pastures or fields where it must be fenced to keep live-stock away. Small corners or parcels of land so cut off by the ditch as to be of little or no value for cultivation or use should be paid for by the district. An illustration of such a case is seen at the north end of G's farm on the map, Fig. 53, where the ditch cuts off a sharp corner between the highway and railroad. Necessary farm bridges are usually built by the district and included in the total cost. If done at private expense they are considered as damages.

If the outlet ditch is a tile-drain, then right-of-way privileges and the cost of crops destroyed or whose planting at the proper season is prevented are the only damages allowed, as an under-drain is no injury to the land.

In some States the law makes it incumbent upon the injured party to claim damages within a specified time, and, if he fails to do this, no damages are awarded. It would seem more just to award damages to all impartially, as benefits are assessed, without requiring claims to be filed.

Highways are also claimants for damages. Where towns construct that part of outlet ditches crossing public roads, the cost of the construction is regarded as damages due the township road fund from the district. A ditch along a roadway obstructs travel and inconveniences the traveling public during its construction. If the excavated material is thrown on the road-bed, extra labor is required to so level and compact it as to make the road fit for use. Often a temporary side-road must be provided to accommodate travel. All of these and other similar exigencies give occasion for just damage claims.

Railroads are allowed damages for the cost of con-

struction of district ditches across their rights of way. New bridges or the substitution of a new one for an old one made necessary by the increased volume of water, present a situation over which there are contentions between railroads and districts, the former holding that districts should pay for a new bridge, or in the case of substitution, the difference in valuation and cost of erection of the two bridges, while the latter hold that the railroad must provide at its own expense whatever bridges are needed to permit the passage under them of all water that may by reasonable and lawful drainage be brought to them, the district only paying for the cost of construction of the channel. A Supreme Court decision in at least one instance where appeal was taken sustains this latter contention.

The engineer may not be directly concerned in the award of damages, but he should keep in close touch with the situation, and be so familiar with the law and with the court decisions in drainage cases that he can make helpful and pertinent suggestions which may materially expedite matters or prevent injustice.

Assessments of Benefits. It is distinctly stated in most drainage laws that assessments upon property for defraying the cost of the work should be in proportion to the benefits conferred. After the cost of the work has been sufficiently determined to show that it will be well below the resulting benefits, such assessment should be made. The manner of doing this is usually left to the judgment of a board whose appointment is prescribed by law and whose duty it is to assess the benefits to each landowner. The engineer is frequently a member of this board and in a position to largely direct the adjustment of the assessments, but if not, he is almost certain to be called upon to assist in the performance of the task. Having been identified with the survey and

familiar with the lands, he should be able to give information which is essential in the consideration of this delicate question, while his training and experience should render his judgment and advice sound and trustworthy. He should enter upon the work not only with a desire to be as fair and impartial as possible, but with a thorough understanding of the principles involved in an equitable assessment, and a knowledge of the absolute and relative values of the factors upon which his judgment must rest. A hasty or superficial performance may result in gross injustice and lead to serious delays and legal entanglements.

Principles Underlying Assessments. The following principles which apply in the determination of assessments upon various properties should not be overlooked by those who are appointed to perform this duty.

An owner is entitled by right of ownership to such natural drainage as his land possesses, and may drain it as he chooses provided he does it within the boundary of his own possessions and discharges his artificial drains into a natural watercourse on his own land.

If the natural outlet for the territory surrounding him is upon his land, he should not be assessed for any part of the cost of cooperative drainage unless it can be shown that he is benefited by the drainage of the adjoining land. If, for example, the slope of the country is such that without the drainage works he would have to take care of the natural drainage of one or more farms above him, of which he is relieved by the construction of the artificial outlet and the drainage of these farms, then the public works will benefit him to a degree depending upon the injury he suffered by reason of the wet condition of the adjoining land. An illustration of this is seen in the case of **H** in the assumed district. (See **Map and Memorandum, Drainage District No. 4, pp.** 268 and 269,

Although the natural outlet is on his land and it is plain that he could have drained without the cooperation of his neighbors, his assessment is quite high. But the slope of the land is such that he receives the drainage of the farms above him. Had not the district drain relieved him, his private drains must have been large and costly to take care of the water discharged upon his land. The outlet ditch and the drains of his neighbors will relieve him to such an extent that the cost of his private drainage will be greatly lessened. For this reason it is fair to make his assessment as high as the wetness of his land calls for, notwithstanding his nearness to the outlet.

If no such condition exists, and no other benefit is apparent, no assessment should be made against him, while damages should, of course, be awarded for the right of way to the outlet on his land. The law provides that such right of way cannot be withheld from a district, but in case no agreement with the owner can be reached, the necessary land may be condemned and the proper remuneration awarded by jury.

A tract of land which is wet and practically useless for agricultural purposes should be assessed proportionately higher if reclaimed by the drainage system than other land in the district which has better natural drainage. Other things being equal, the greater the injury to the land from water, the higher should be the assessment if it is fully reclaimed.

A tract which lies distant from a natural outlet may be assessed higher than one lying near, if both receive the same drainage advantages, on the ground that the former has had brought within its reach by the construction of the artificial outlet what the latter possessed without it, but only when such land has little or no natural drainage.

Outlet privileges should be assessed in proportion to the distance of the lands from the ditch, as upon that will depend the length of lines and consequent cost of private drains to complete the drainage.

In case a public drain incidentally passes through a farm for the purpose of giving more perfect drainage privileges to adjoining land, and in so doing affords direct drainage to the farm, and also lessens the expense which will be required to complete its drainage, the farm should be assessed proportionately higher than the land adjoining because private drainage has been accomplished at public expense.

If a drainage district does not furnish complete outlet for the lands of the entire tract, those which receive only partial drainage should be assessed proportionately less.

If within the limits of a district are soils of widely differing fertility, some of which are capable of producing high-priced market-garden crops, while others have but little or medium fertility, the fertile lands, other things being equal, should be assessed the highest, because the value of the drainage is greater to such land.

The land occupied by right of way should not be assessed for benefits as it will yield its owner no future returns, but the number of acres so used on each property should be deducted from the total acreage of that property and not appear on the assessment sheet. However, while this is correct in principle, the amounts involved, except in costly improvements and large individual holdings, are so small that this point is usually ignored.

Methods of Assessing Benefits. In this important part of organized drainage operations, it is desirable that a general scheme or plan be followed in order that equitable ratios of benefit shall be secured for all lands

throughout the district. Current practice in this varies greatly, and the principles underlying each method should be studied critically before deciding upon the one best adapted to the case in hand. The value of any method, however, depends largely upon the judgment of those using it.

Drainage Districts organized under the State laws are permitted to issue interest-bearing bonds to provide funds to finance the work, and the assessed property in the District becomes security for the payment of the bonds and the accrued interest. Where this is done the benefits must be definitely assessed and should be about twice the estimated cost of the work since the measure of benefits fixes the limit of the tax that can be levied, and bond buyers demand a safe margin for security of the bonds.

A brief description of the principal methods employed in assessing the benefits are here given. Some of the State laws prescribe the method which shall be used; in other States the Assessment Board is left free to choose its own method. The first three methods mentioned apply to the distribution of cost without any assessment of benefits other than determining in a general way that the benefits will exceed the cost.

Arbitrary Assessment of Cost. By this method the cost of the improvement having been estimated and found to be less than the benefits that will accrue, the amount of cost that should be assessed against each property is determined by the board or officer of the law appointed for the duty, by inspection, comparison, and trial, the endeavor being to proportion the assessment of costs to the benefits. In practice, the estimated average cost per acre of the proposed improvement is taken as a basis, and changes above or below this amount are made to correspond with the variations in benefit which

will be conferred upon each property. In case the amount levied is not sufficient, a second assessment is made upon the same basis; if the amount is too great, a rebate is distributed. This is the oldest method of making special assessments, and in the hands of a well-informed board that will canvass the entire situation carefully, gives satisfactory results for small districts where bonds are not issued. If the examination is superficial or the members of the board do not understand the benefits accruing from the construction of drains, unjust assessments may be made.

Assessment of Cost According to Value of Property, or Ad Valorem. Assessments made in this manner assume that the improvement is of a public nature, and that its cost should be provided for in the same manner as other taxes. Assessments for the cost of levees are sometimes made upon this basis on the theory that the benefit of the improvement is in proportion to the value of the property protected.

A Flat Rate or Uniform Charge per Acre. Such an assessment is sometimes made upon the lands of an entire district when the benefits of the improvement are fairly uniform, as may be the case on lands where a levee is constructed to protect them from inundation by tide or river; or where a natural stream is improved in such a manner as to uniformly benefit the lands of an entire valley.

In the following methods the benefits are more or less definitely assessed upon each tract of land, and the cost distributed proportionately. In some cases simply a ratio is established according to benefit by which the cost is apportioned, but the placing of a money value upon the benefits assessed is practically required by some State laws, and has advantages which are bringing

it into favor with engineers and Assessment Boards even when not so required.

Difference in Value Before and After the Improvement. In this method of assessing the benefits the value of the properties before and after the public drain has been constructed is estimated and their difference is made the basis of the assessment. A tract of land estimated worth $1,000 before drainage and $1,800 after, is assessed $800 benefit, and if the cost of the work is one-fourth of the total benefit, it pays $200 as its proportion of cost. The difficulty in applying this method, particularly in a large district, is in making uniform and equitable valuations throughout, and in anticipating the increase in value which will result directly from drainage. In working out the method, the total cost to be distributed is divided by the total estimated benefits. The result is the amount which each dollar of benefit costs. The estimated amount of benefit to each property multiplied by this quotient gives the total cost each pays. This method is worked out on the Assessment Sheet of Drainage District No. 1, page 256.

Distribution of Cost by Division of Land into Classes. Several State laws specify that the lands shall be divided into five classes (in one instance, three), in which the benefits per acre shall be represented in the ratio of 5, 4, 3, 2 and 1. The classes are designated as A, B, C, D and E, and in the distribution of cost, lands in Class A pay $5.00 per acre when those in B pay $4.00, C, $3.00, D, $2.00, and E, $1.00. These laws do not require an assessment of benefits, but the district may be established by the board of commissioners after they have satisfactory evidence that the benefits in general will exceed the cost and that the work will be conducive to the public welfare. It is advisable, however, to estimate the benefits, and the sale of bonds will be greatly

DRAINAGE DISTRICT NO. 1

Assessment Sheet

Value Before and After Drainage

1	2	3	4		5	6 (Left blank by Assessor) APPORTIONMENT OF COST. $0.24 = Cost of $1 of Benefit.	
			VALUATION.				
Owner	Description of Land	Number of Acres	(a) Before	(b) After	Assessment of Benefits in Dollars	(c) Per Tract	(d) Per Acre.
A		80	$800.00	$4,000.00	$3,200.00	$768.00	$9.60
B		120	3,600.00	7,200.00	3,600.00	864.00	7.20
C		160	3,200.00	8,800.00	5,600.00	1,344.00	8.40
		40	1,600.00	2,400.00	800.00	192.00	4.80
D		180	4,500.00	9,000.00	4,500.00	1,080.00	6.00
E		60	600.00	3,000.00	2,400.00	576.00	9.60
F		2 town lots	300.00	420.00	120.00	28.80	14.40 (each lot)
Total.	......	640 acres	....	....	$20,220.00	$4,852.80	

$$\frac{\$4852.80}{20220} = \$.24 = \text{Cost of } \$1 \text{ of Benefit}$$

Total cost of improvement	**$5,100.00**
Highways	**247.20**
Landowners	**$4,852.80**
Average cost per acre to Landowners	**7.54**

DRAINAGE DISTRICT NO. 2

Assessment Sheet

Lands Divided into Classes.

Class A = 5. Class B = 4. Class C = 3. Class D = 2. Class E = 1.

1	2	3		4		5	6
Owners	Description of Land	Number of Acres		Classification (a) Class	Classification (b) Ratio	Equivalent Number of Acres in Class E	(Left blank by Assessor) Apportionment of Cost $.94 = Cost of Improvement to 1 acre of Class E
			80	A	5	400	$376.00
M		160	60	C	3	180	169.20
			20	E	1	20	18.80
			100	A	5	500	470.00
N		185	25	B	4	100	94.00
			60	D	2	120	112.80
			200	B	4	800	752.00
R			100	C	3	300	282.00
		440	80	D	2	160	150.40
			60	E	1	60	56.40
		160	100	C	3	300	282.00
S			60	E	1	60	56.40
Total.	......	945		....	....	3,000	$2,820.00

$\frac{\$2820}{3000} = \$.94$ = Cost of Improvement to 1 acre of Class E

Total cost of improvements..................		$3,200.00
Highways, 5 per cent...........	160.00	
Town Lots.....................	220.00	
		380.00
Landowners..........................		$2,820.00

Cost per acre: Class A, $4.70; B, $3.76; C, $2.82; D, $1.88; E, $.94

Average cost per acre to Landowners, $3.00.

facilitated when this is definitely done. The method is fairly well adapted to some lands, but lacks elasticity, because the variation of benefits conferred is frequently greater than can be indicated by only three or five classes, and injustice is done those whose benefits are less than a third or fifth of the maximum. Additional classes to accommodate a greater variety of degrees of benefit may be introduced when not prohibited by law, and the results worked out in the same manner.

Before the lands in the district can be assigned to their proper classes, the location and kind of drains, and their relation to each tract of land must be determined and a map prepared on which these are clearly indicated. The wetness of land in each tract, its completeness of outlet and proximity to the ditch should be considered, with any other factors, such as fertility of soil or distance from a natural outlet, which should have weight in the particular district in question.

An assessment sheet for an assumed district, **Drainage District No. 2**, is given on page 257 to illustrate this method. The product of the number of acres in a tract by the ratio of the classes to which it has been assigned, gives an equivalent number of acres in Class **E**, or with a ratio of one.

When the estimated cost of the project is known deduct any lump sum assessments there may be and divide the remainder by the sum total of **Column 5** and the quotient will be the cost of the improvement to one acre of Class **E**, by using which as a multiple throughout **Column 5** the cost is properly distributed to each tract (**Column 6**). If it is desired to express the estimated benefit in dollars, a definite value may be given benefit per acre to land with a ratio of **5**, and a column prepared after the manner of **Column 5** on Assessment Sheet of **Drainage District No. 4**, and substituted for

Column 5 on this sheet, the multiple then used in filling the Cost column being the quotient obtained by dividing the total cost by the sum total of division (b) of the substituted column.

Classification by Comparison, on a Basis of 100. The requirement made by the drainage laws in some States that the estimated benefits from the proposed drainage to each tract of land shall be expressed in definite sums in order that the excess of benefit above cost be shown, is not recognized in this system of classification. The drainage district is considered a quasi-public organization, and benefits upon which the establishment of the district depends should be estimated in the aggregate. In prosecuting a work of this nature some interests may be benefited but little or not at all, yet the aggregate advantages may fully warrant the undertaking.

Classification of land on a basis of 100, as required in some State laws, is as follows: Select the farm, 40-acre tract or any other representative unit which receives the maximum benefit by reason of the proposed improvement, and indicate its classification, as well as that of other tracts equally benefited, by 100. Compare all other tracts in the district with this and rate each according to the relative benefit it will receive compared with the one marked 100. The various factors composing the benefit are taken into account, as in other methods, and also a map prepared. With this in hand, those appointed to classify the lands examine the ground critically and record the ratio of each tract before leaving it. The members of the board form their judgments independently and then, while still on the ground, compare their markings, and review conditions, if necessary, until they agree on a classification that they believe will be equitable and just.

The assessment sheet for a district prepared by this method is shown for **Drainage District No. 3**, page 262. In this assumed case the land is divided into 40-acre tracts as required by some State laws, and there being no fractional tracts, size does not enter into the comparison, and the column of classification represents also the units of benefit, thus simplifying the computations. It is not necessary, in order to apportion the cost, to give any value to the units of benefit, though this may be done as in other methods. The cost of a unit, which is comparatively large because for 40-acre tracts, is found by dividing the cost of the improvement after deducting lump sums, by the sum total of the units of benefit.

If bonds are to be issued, it will be desirable, and perhaps necessary, to give a definite value to benefit per 40-acre tract on lands graded 100, and prepare a column after the manner of (b), **Column 5**, on Assessment Sheet of **Drainage District No. 4**, and insert between **Columns 4** and **5** on this sheet, the multiple then used in filling the **Cost** column being the quotient obtained by dividing the total cost by the sum total of the inserted column.

If tracts of land unequal in size are compared, a column must be introduced between **Columns 4 and 5** which shall contain the product of the ratios, **Column 4**, by the number of acres in each tract, from which the cost is apportioned as before, by multiplying throughout by the quotient arising from dividing the total cost after deducting lump sums, by the sum total of this inserted column.

Assessment According to Percent of Benefit. This method is the most recent, but the most scientific and systematic, and it is believed, when rightly applied, gives the fairest results. It has been adopted by many of the best engineers, and its use is recommended whenever another method is not prescribed by law. The estimated degree

of benefit which each tract receives is here made the basis of the apportionment of cost, 100 per cent representing the maximum in the district, and 0 the absence of all benefit.

The different factors of benefit, which have more or less weight in all the methods in the determination of relative benefits, are here given a more definite and important place, being taken up separately and assigned a percent which indicates the proportion of maximum benefit that each tract receives under that factor in the judgment of the engineer or board. The several percents of each tract are then multiplied together to form its total percent of benefit.

For example, **natural wetness of land** and **completeness of outlet** afforded by the ditch are factors of benefit. A tract may be marked 60 per cent under the first, and 80 per cent under the second, which expresses the judgment of the assessor that it receives only 60 per cent of the maximum benefit under **wetness** and 80 per cent under **completeness of outlet**, making the total benefit 80 per cent of 60 per cent, or 48 per cent of maximum benefit.

The method is an attempt to reduce assessments or benefits as far as possible to an analytical process. If used with good judgment it gives equitable and satisfactory results. It will at times, perhaps, be found difficult to express all benefits by definite factors in such a manner that the ratio of benefit can be worked out with arithmetical precision. It enables the assessor, however, to treat the subject systematically and keep before the mind the principles that should be applied in every case. As conditions are seldom alike in any two districts, no hard and fast rule can be followed.

Since the factors constituting benefit are not the same in all districts, their determination should be a subject

DRAINAGE DISTRICT NO. 3

Assessment Sheet

Classification by Comparison. Maximum 100.

1	2	3		4	5 (Left blank by Assessor) Apportionment of Cost $2.25 = Cost of 1 Unit of Benefit	
Owners	Description of Land	Number of Acres.		Classification; also Units of Benefit	Per Tract	Per Acre
			40	100	$225.00	$5.63
K		120	40	80	180.00	4.50
			40	60	135.00	3.38
			40	40	90.00	2.25
			40	90	202.50	5.06
L		200	40	90	202.50	5.06
			40	25	56.25	1.41
			40	15	3.38	.84
O		40		80	180.00	4.50
			40	35	78.75	1.97
P		160	40	5	11.25	.28
			40	75	168.75	4.22
			40	20	45.00	1.12
T		80	40	50	112.50	2.81
			40	25	56.25	1.41
			40	10	22.50	.56
			40	60	135.00	3.38
W		240	40	100	225.00	5.63
			40	100	225.00	5.63
			40	80	180.00	4.50
			40	60	135.00	3.38
Total.	. . . .	840		1,200	$2,700.00	

$\frac{\$2700}{1200} = \$2.25 =$ Cost of 1 Unit of Benefit.

Total cost of improvements		$3,100.00
Highways, 6 per cent	$186.00	
Railroads	214.00	
		400.00
Landowners		$2,700.00

Average cost per acre to Landowners, $3.21.

DRAINAGE DISTRICT NO. 4

(See Fig. 53.)

Assessment Sheet

According to Percent of Benefit

1	2	3		4	5		6 (Left blank by Asses'r)	
					Assessment of Benefit in Dollars 100 per cent = $20 per Acre		Apportionment of Cost $.155 = Cost of $1 of Benefit	
Owners	Description of Land	Number of Acres		Per-cent of Benefit per Acre	(a) Per Acre	(b) Per Tract	(c) Per Tract	(d) Per Acre
A		80		.140	$2.80	$224.00	$34.72	$ .43
B		220	90	.900	18.00	1,620.00	251.10	2.79
			70	.405	8.10	567.00	87.88	1.25
			60	.128	2.56	153.60	23.81	.39
C		120	20	.900	18.00	360.00	55.80	2.79
			50	.637	12.74	637.00	98.73	1.97
			50	.130	2.60	130.00	20.15	.40
D		160	40	1.000	20.00	800.00	124.00	3.10
			60	.648	12.96	777.60	120.53	2.01
			40	.204	4.08	163.20	25.30	.63
			20	.120	2.40	48.00	7.44	.37
E		200	80	.900	18.00	1,440.00	223.20	2.79
			60	.640	12.80	768.00	119.04	1.98
			50	.240	4.80	240.00	37.20	.74
			10	.130	2.60	26.00	4.03	.40
F		240	70	.900	18.00	1,260.00	195.30	2.79
			140	.499	9.98	1,397.20	216.57	1.55
			30	.156	3.12	93.60	14.51	.48
G		300	150	.900	18.00	2,700.00	418.50	2.79
			75	.720	14.40	1,080.00	167.40	2.23
			75	.256	5.12	384.00	59.52	.79
H		280	90	.800	16.00	1,440.00	223.20	2.48
			100	.641	12.82	1,282.00	198.71	1.99
			80	.292	5.84	467.20	72.42	.90
			10	.176	3.52	35.20	5.46	.55
Total.		1,600				$18,094.05	$2,800.00+	

$$\frac{\$2800}{18094.05} = \$.155 = \text{Cost of } \$1 \text{ of Benefit}$$

Total cost of improvements		$3,200.00
Highways, 5 per cent	$160.00	
Railroads	240.00	
		400.00
Landowners		$2,800.00

Average cost per acre to Landowners, $1.75.

of especial consideration. Besides this, the weight each should receive varies, thereby necessitating particular care in assigning the percents of value to each so that their effect on the total shall be relatively equitable and correct.

It may be observed that certain factors are component parts of the benefit. They are **wetness of land,** which determines the need of drainage; **proximity to the drain,** which determines the cost of additional drains to complete the drainage; **completeness of outlet,** which determines the degree of thoroughness of drainage made possible by the district outlet drains; and the **fertility of the soil,** which affects the value of the improvement to each tract. To these may be added, **distance from a natural outlet,** which affects in a minor degree the need of the improvement; and **difference in location,** which affects the degree of benefit, as in the case of lands which are near a town or city and by reason of this may become residence or factory sites, while others have only country surroundings: these and other factors may or may not enter into the final estimate of benefits.

In determining the weight of a factor it should be noted that 0 **per cent** does not mean the lowest degree of benefit which may exist in the district, but the entire absence of benefit. In the case of **proximity to the drain,** for instance, those lands farthest distant should not be rated 0, for it is evident that their benefit is still considerable. In this regard only lands entirely out of the district can be said to receive no benefit. Those near the border of the district may perhaps properly receive from 50 to 60 per cent by reason of proximity to drain, making the range of this factor only between 50 and 100 per cent.

Distance from a natural outlet, when it enters as a factor, should not be given a wide range. Except in districts whose upper part is so level as to have little or no natural

drainage the benefit received by the upper lands, in having the outlet brought within reach, is practically offset by the benefit received by those at the lower end in being relieved of the water from lands lying above them, and distance from the outlet should not be considered a factor.

In the case of **fertility of soil**, it is possible that there will be a tract in the district which is entirely devoid of fertility and should be rated at 0, in which case the total percent of benefit to that land would be reduced to 0. But other lands in the district may vary so little from the maximum in this respect that 80 to 100 per cent would fairly represent the range.

Under **wetness of land** a tract may be given a 0 rating if by any chance one requiring no drainage falls within the district. This rarely occurs and the minimum benefit does not usually fall below 20 per cent or 10 per cent at the least, though lands with the maximum wetness are found in every district.

Completeness of outlet, also designated as **thoroughness of drainage**, refers to the capacity and depth of the ditch with reference to its efficiency as an outlet to the lands it serves. District plans do not always provide outlets that will fully meet the needs of every tract. It is not common for this factor to become 0, because some relief will usually be given even by a defective outlet, while it should be possible, ordinarily, to give the maximum rating of 100 per cent to all lands in well-designed districts. Benefits in this particular may, however, range from 100 per cent to 50 per cent, and possibly lower, observing that a few intermediates will express varying degrees of benefit as closely as it is possible to estimate them.

In regard to the whole question of range which should be given each factor, and the latter's consequent weight

in the total estimate of benefit, it may be suggested that in order to determine this in any doubtful case, consider a supposed or actual situation in which all other factors are 100, and judge what is the least degree of benefit lands in the district under consideration should be considered to receive if controlled by this factor alone. For instance, if fertility is the factor in question, consider a tract of land having the least fertile soil in the district, and determine what proportion of maximum benefit it receives from the improvement if all other factors are 100. This will establish a minimum percent for this factor in this district.

A practical way to learn the effect of different weights in factors, or changes in factor percents, is by trial on a real or assumed district. Experiment at length by varying the range of factors and altering the percents, being careful to compare results and note how the total percent is affected. This will assist one to intelligently adjust the weights of the factors and determine the just factor percents.

It may be found that in order to properly meet special cases where local conditions demand it, some small additions to or subtractions from the total percent obtained by multiplication of the factor percents, will be necessary.

This discussion will serve to show the difficulties and dangers in reducing assessment of benefits to a strict arithmetical process. As before said, the practical value of the method depends upon the amount of judgment and common sense exercised in its use. It must not be so rigidly carried out as to sacrifice in any degree the rights of the landowners.

As in all other methods, too much emphasis cannot be placed upon the importance of performing the work on the field, and not in the office. It is only through actual knowledge of existing conditions gained from personal

reconnoissance and inspection of the entire district, that justice can be even approximated. The percents of benefit under each factor should be assigned on the ground, with a map of the proposed work at hand as a necessary part of the field equipment, for from it the relative elevations of the surface and bottoms of the drains, as well as the distance of the several tracts from their outlets are obtained, and these are necessary points in deciding upon the percents.

The Assessment Sheet for **Drainage District No. 4,** page 263, illustrates this method. The percents under each factor are not shown on this, as it is preferable to omit them on the Assessment Sheet filed for public inspection because liable to be confusing or lead to unprofitable discussion. They are given as a private **Memorandum,** page 269, and in connection with the map, **Fig. 53,** show how **Column 4** is obtained. Only three factors seem to call for consideration in this small district. Complete outlet is provided for all the land, so that factor need not enter, as it would be 1.00 throughout. There is quite a fall from the upper to the lower end and the benefits received by those at the upper end are thus well balanced by others received by those at the lower end, and the distance from natural outlet can therefore be ignored.

A definite value is given the estimated benefits on this Assessment Sheet as required by some laws, as almost necessary when bonds are to be issued, and as desirable in all cases. If, however, it is desired for any reason to apportion the cost without assessing the benefits in dollars, it may be done by substituting for **Column 5** of this Sheet, a column found by multiplying the amounts in **Column 4** by the number of acres in each tract. The cost, $2,800, divided by the sum total of the substituted column, 904.68, gives $3.10, which, used as a multiple throughout that column, will apportion the cost to each

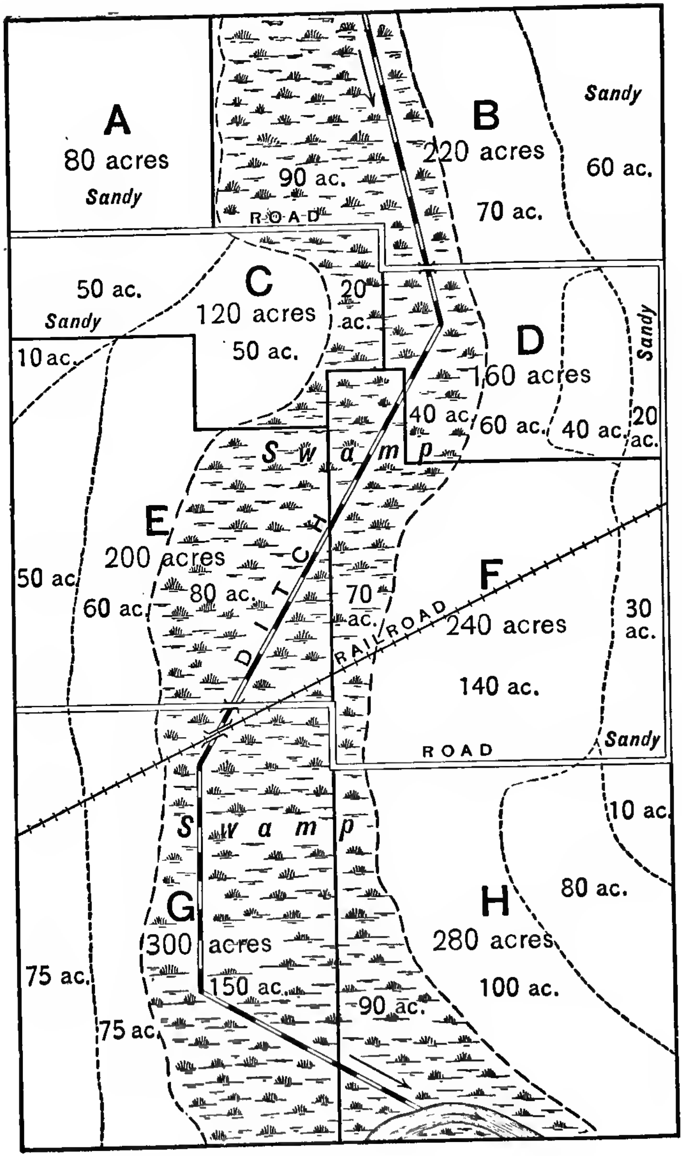

FIG. 53.—MAP OF DRAINAGE DISTRICT NO. 4.

MEMORANDUM

(See Fig 53.)

1	2	3		4			
				Classification According to Percent of Benefit			
Owner	Description of Land	Number of Acres		(a) Wetness	(b) Proximity to Drain	(c) Fertility	(d) Total Percent Per Acre
A		80		.25	× .70	× .80	= .140
B		220	90	1.00	× .90	× 1.00	= .900
			70	.50	× .90	× .90	= .405
			60	.20	× .80	× .80	= .128
C		120	20	1.00	× .90	× 1.00	= .900
			50	.75	× .85	× 1.00	= .637
			50	.25	× .65	× .80	= .130
D		160	40	1.00	× 1.00	× 1.00	= 1.000
			60	.80	× .90	× .90	= .648
			40	.30	× .80	× .85	= .204
			20	.20	× .75	× .80	= .120
E		200	80	1.00	× .90	× 1.00	= .900
			60	.80	× .80	× 1.00	= .640
			50	.40	× .75	× .80	= .240
			10	.25	× .65	× .80	= .130
F		240	70	1.00	× .90	× 1.00	= .900
			140	.70	× .75	× .95	= .499
			30	.30	× .65	× .80	= .156
G		300	150	1.00	× .90	× 1.00	= .900
			75	.80	× .90	× 1.00	= .720
			75	.40	× .80	× .80	= .256
H		280	90	1.00	× .80	× 1.00	= .800
			100	.90	× .75	× .95	= .641
			80	.50	× .65	× .90	= .292
			10	.40	× .55	× .80	= .176

landowner, as under (c), **Column 6**, of the Assessment Sheet.

It will be understood in all the Assessment Sheets, that the last two columns, the apportionment of cost, are filled in later by the proper official, and form no part of the assessment of benefits. The work of the Assessment Board ends with the assessment of benefits in some form from which the cost, when known or estimated, can be correctly apportioned. The Column, **Cost per Acre** is not necessary, but is of interest.

Assessment of Irrigated Lands. Where the territory included in drainage districts is irrigated land, the origin or cause of wet, or seeped, lands should be taken into account. In such localities the necessity for draining is due to water coming to them by percolation through the soil and by waste over the surface from adjoining higher lands, such water having been applied for irrigation.

It is held by many in the irrigated sections that while the owners of higher lands are in no way benefited by the drainage of those lower, they are responsible for the condition of the latter, and should be assessed for a part of the expense, because the water which passes from the higher lands is brought to them by artificial instead of by natural agencies. This proposition is agreed to in some instances, and a part of the cost of draining the lower lands is assessed against the higher. The principle is generally recognized, however, that the holders of the lands requiring drainage must protect themselves against the seepage and waste of those which by nature occupy a dominant position.

Actual benefits from draining a wet tract often extend to lands on a lower level, but quite distant from it. This is due to the interception of the seepage which would otherwise injure the lower lands and these are, therefore,

benefited although no drains are constructed upon them nor a drainage outlet given them. Lands thus benefited may be assessed for a proportionate part of the cost of drains, for the same reason that lands are assessed for the cost of levees which protect them from overflow.

Conclusion. The several methods of assessing benefits and apportioning the cost of drainage works where cooperation of property owners is required in constructing and maintaining them have been carefully reviewed because no division of the work is more important. A failure to equitably distribute the cost has led to untold dissensions, litigation and delay in district proceedings. As the principles become better understood and the methods of applying them more systematic and logical, the difficulties assume less perplexing proportions.

It is urged that those who are charged with the duty of making assessments examine all of the methods carefully, that the leading and controlling elements which have a bearing upon the subject become thoroughly understood and appreciated. They should also be familiar with court decisions upon what constitute assessable benefits, and know of any limits placed upon special assessments by local laws.

As a final word upon this subject, it may be said that in no part of drainage work is there demanded more conscientious service on the part of engineers and assessment commissioners. The consequences of careless or ill-considered findings are so serious to property owners, and often, incidentally, to the progress of a meritorious and needed reclamation project, that too great care cannot be exercised.

Assessments of Railroads. It is apparent that the drainage tax upon railroads cannot be levied on the same basis as that upon farm lands. The usual method is to assess them a lump sum which by law must be propor-

tioned to the direct benefits received. To arrive at a conclusion as to what shall constitute a just amount, three things should be considered: the number of miles of railroad benefited, the amount of benefit received, and the total cost of the drainage improvement.

The number of miles benefited may not include the total length of the road in the district, as not all of it may be through wet land.

Among the direct benefits which should be counted, the following have been sustained by the courts: increased solidity of the roadbed; less danger of its settling because of boggy soil foundation; less liability of damage to the track from freezing and thawing of roadbed; fewer culverts and long trestles to maintain; decrease in cost of maintenance of roadbed; greater stability of fences and poles; and greater freedom from aquatic rodents that do much damage to a roadbed when water stands beside it.

The cost of the improvement should be taken into account for the reason that the size of all other assessments in the district is governed by it, since they are a certain percent of it.

Many railroad companies appreciate the value of drainage to their lines and to the territory from which they draw their traffic, and are ready to bear the share of cost justly apportioned to them, even going so far, in some instances, as to take the initiative in promoting such improvements.

Inter-urban lines are subject to assessments determined in the same manner as those for railroads. Telephone lines across country are benefited by drainage in convenience and ease of maintenance of the line, and in increased stability of poles.

Assessments of Public Highways. The actual betterment of the highway which is accomplished by the

drainage system of the district is the basis upon which public roads should be assessed. The construction of main drainage courses through a wet or swampy portion of the district crossed by a road renders all necessary embankments more stable and enduring, reduces the expense of maintenance due to settling and flattening of the banks, and eliminates many small culverts and long trestles formerly required for the passage of water, by the construction of one substantial bridge over the main channel. It removes standing water from the right of way and permits the shaping of the latter so that it can be easily mowed and thus kept free from noxious weeds.

By the improvement of bad portions of the roads the entire system is made uniform in excellence and a substantial and lasting benefit is conferred upon the community at large. In this sense the improvement of a small part of a road benefits the whole as a highway, and all who travel over it. For that reason the assessment may be placed at a comparatively high figure, particularly since it is paid by all property owners of the township or county upon its assessed valuation, in common with other taxes. As in the case of railroads it should bear a ratio to the cost of the work. For this reason an equitable method is to assess the highway a certain percent of the entire cost of the work based upon the length of road benefited and the degree of benefit. This should be deducted as a lump sum from the whole amount before the assessment is distributed over the farm lands, the percent being shown on the assessment sheet.

Assessments of Town Lots. Town lots cannot be assessed on the same basis as farm lands. If there are only a few included in the district they may each be assessed a lump sum according to their relative size and

the degree of benefit, always remembering that the total cost of the drainage works should be taken into account as in railroads and highways. If a town, or any considerable portion of one, is included in a drainage district a method of classification of the lots should be adopted to meet the conditions. Usually a flat rate for a certain size of lot is adopted and all lots are assessed on that basis, if the benefit is practically the same. Sometimes the value of the lot should affect the amount of assessment.

CHAPTER XVII

LEVEE DRAINAGE SYSTEMS

Among the large projects which drainage engineers are being called upon with increasing frequency to examine and develop are those requiring the construction of levees either to protect interior lands from overflow of streams, or coast lands from the encroachments of the sea.

Protection and Drainage of River Bottom-Land. The topography of river bottom-land is such that a levee district along a stream is comparatively narrow, but may extend miles in length. Its width will be the distance between the stream and the nearest bluffs or high lands running parallel with it on one side, while its length may be from one large tributary of the main stream to the next, entering on the same side. Whatever its dimensions, the levee must so supplement the bordering high land as to thoroughly protect the enclosed area from overflow. Usually this will require its construction on three sides of the district, that is, along the stream and across each end, from the river to the bluff. But this protection from outside waters serves as well to prevent the escape of surplus water from the land by natural channels, and hence provision for the interior drainage of the area is necessary. This must be so planned as to care not only for the direct rainfall upon the tract, but also in some cases for the water flowing from the adjacent high lands which may discharge upon it. Under some conditions seepage water percolating under the levee from the river must also be guarded against.

The long stretch of levee required, in proportion to the area protected, the drainage system necessary, including sometimes a costly pumping plant, the continuous annual outlay for operating the pumps and maintaining the levees and ditches, all combine to make this method of reclamation more expensive than any other ordinarily used. For this reason, only land whose returns after reclamation will warrant so great expense should be thus treated. The successful engineer will bring to bear upon such undertakings his most careful consideration and utmost skill. A thorough study of the entire situation, as well as of other problems similar in character which have been successfully worked out elsewhere should precede the actual work upon the ground.

Preliminary Survey. The preliminary survey for a levee district consists in running a series of level-lines across the proposed territory, as elsewhere described (See **Survey of Valleys, Chap. V**), thus locating ridges and depressions of surface; in meandering streams or water-courses of any considerable size within its limits; and in taking sufficient levels upon the adjacent high lands to determine the boundaries of the watershed whose waters discharge upon the district. In addition to these data secured by instrument-work, the engineer must have all available records of the amount and distribution of the precipitation over the section of country under consideration, the high-water marks of the streams to be leveed, and estimates of the runoff for which outlet must be provided. The existence of any natural depressions or streams which may be utilized as drainage channels by means of sluice gates, should be noted.

The Location of the Levee. As has been said, the protective levee ordinarily extends continuously around three sides of the district, but its exact location as to distance from the river in order to secure a solid founda-

tion and to leave the right amount of floodway for the stream are questions of great importance to be settled by the engineer according to local conditions for which only general directions can be given. The volume of flood-water, its velocity, the nature of the soil composing the banks, the elevation, slope and stability of the ground in the vicinity of the levee are the factors which enter into a determination of its correct location. The general direction of the levee should be parallel to the stream, but this may be varied to take advantage of higher or more stable land, being particular to make the changes in direction by easy curves rather than sharp angles. The distance between the river side of the borrow-ditch and the river's edge, or the width of the strip of land left undisturbed between the river and the borrow-pit, will depend largely upon the nature of the banks, their stability and freedom from erosion, as also upon the volume of water for which a channel must be provided, but fifty feet is the minimum width that should be allowed. It often happens that the land along a river slopes quite sharply away from the bank, so that the levee must be built considerably higher when located at some distance from the stream than if placed near the bank. In such cases this consideration must enter into the decision of the location, as one affecting quite materially the expense as well as the stability of the work. The closeness of the levee to the bank depends much upon the size of the stream and particularly upon the length of time that the water will stand against the levee. It should be located on stable ground where there is sufficient room for the necessary berm and borrow-pit on the river side, should avoid places which are exposed to erosion by currents and waves, and should cross sloughs and old channels by the shortest courses.

Dimensions. The height, width of crown and side slopes should each receive critical attention, as the safety of the levee depends upon them. Different levees vary in height from 4 feet to 20 feet, according to the height of flood to be provided for, while the same levee may run from 20 feet high at its highest part to 0 where the ends meet the high ground. The important point is to have the crown throughout its entire length at least 3 feet above the flood-plane of the stream, to guard against injury by possible higher floods or by wind waves should the levee adjoin open water. It will be found that the flood-plane takes the general slope of the valley, so that the crown should have a corresponding slope. This slope should be determined from high-water marks found at the time the survey is made. The return-levees, those extending from the river to the bluffs, should be carried back upon a level unless they follow a tributary stream which brings water from the bluffs, in which case their crown should be parallel to the flood-plane of the stream as in the main levee. If there are no flood records obtainable, or if a levee is to be built on the opposite side of the river also, then computations of volume of estimated flow during flood periods must be relied upon, and if data for these are meager or uncertain then a larger margin should be allowed for height of levee. A levee higher than necessary will be less costly than one too low, if there must be a discrepancy either way. The general height of levees is from 8 to 16 feet.

The breadth and slope necessary to secure strength and durability depend in part upon the material of which a levee is built, as well as upon the method of construction. A tough, gumbo soil is the most satisfactory material. The minimum dimensions for one of this kind are a width on top of 6 feet, a slope on the river side

of from 2 to 1 to 3 to 1 (preferably the latter), and on the land side of 2 to 1, though 3 to 1 here is also better. If the material is sandy, or if the side of the levee is to be subjected to strong currents or wave action, flatter slopes must be used. A slope not steeper than 3 to 1 on both sides lessens the difficulty of keeping the levee in repair.

Construction Survey. The survey consists of staking out the center line for the levee in the same manner as that for a ditch. Levels are taken at each station and a profile of the surface of the ground made, upon which is established the crown line of the levee, after which the fill at each station is computed. Slope-stakes should be set at each station to mark the location of the toe of the levee on each side. Frequent bench-marks should be placed at convenient points for the use of the engineer in making estimates of the amount of work from time to time, and for setting the final stakes on top by which the levee is to be finished. The method of surveying and of computing the cubic yards of fill are the same as that required for ditches.

Construction. The first step in the construction of a levee is to remove all vegetation from the strip of land to be occupied by the embankment, including the grubbing of stumps and roots to the depth of 3 feet, and the refilling with solid earth of the holes thus made. Fill all ditches crossing the embankment with solid earth up to the line established for the base of the levee. Such filling must extend not only under the foundation but across the berm, and for 10 to 20 feet on the land side of the embankment. Plow the surface of the site of the levee leaving a dead furrow in the center. If the levee is of firm and dense material, its height moderate, and exposure to the action of water occurs only at infrequent intervals, this plowing may be all that is necessary to

prepare the foundation. But if for any reason extra precaution is advisable, dig a continuous muck ditch under the center line of the levee. This should be from 3 to 4 feet deep, or even deeper, if there is danger from seepage at lower depths. It should be filled with a clayey mixture, well compacted and entirely free from all vegetable matter. This latter is an important point, and applies equally to all material used in the construction of the levee. A well-prepared foundation removes one of the most frequent causes of defective levees.

Build up the embankment with scrapers, dipper-dredges or drag-bucket machines, each method having its advantages and its advocates. A more symmetrical levee can be made with scrapers. Those made with steam-dredges can be constructed more rapidly, and, if the earth is carefully distributed when deposited, are more compact and solid when completed than those made in any other way.

An allowance should be made for shrinkage which takes place from the time the levee is finished until the earth assumes its permanent position. Where levees are made of dry earth by team labor in the ordinary way, 10% is allowed for this. When made with a steam-dredge much less shrinkage occurs. When earth is taken from the borrow-pit, where it is said to be "in place," and deposited in an embankment, it increases in volume about one-fifth part, after which it settles and occupies less space than it did before being dug. These facts should be remembered when the temporary and permanent grade for the crown are established. The number of cubic yards of fill paid for when the work is done by contract is the amount contained in the embankment as finally required.

Borrow-Pit and Berm. With any method of con-

struction the material must always be taken from the river side of the embankment, with a clean berm not less than 10 feet wide between the inner edge of the borrow-pit and the toe of the slope. The borrow-pit must be shallow on the side toward the levee, its side slope never being steeper than the slope of the levee, that the latter may not be undermined. It should not be deeper than 3 feet at this side, with a bottom slope of 7 to 1, and whatever width may be necessary to furnish sufficient earth for the embankment, but the greatest depth should in no case exceed 10 feet. Where there is danger from action of strong currents, it is well to prevent this when practicable by leaving bars or "traverses" of undisturbed ground, from 10 to 20 feet in width, nearly across the borrow-pit, at intervals of 250 to 300 feet, which will serve to check the current near the levee.

Intercepting Drain. Where the water stands against the levee for some time, there is danger from seep-water which makes its appearance on the inner side of the levee. This is particularly true if the soil is a sandy, permeable loam. A six-inch tile-drain placed 4 feet deep and 8 feet inside the inner toe of the levee will serve to intercept much of this water as well as to make the base of the levee more firm. Such a drain must discharge into the drainage ditches at every practicable point, since but little grade can be given to it.

Fig. 54 is a cross-section of a levee showing shape of embankment, borrow-ditch, etc., and location of tile-drain just mentioned.

Maintenance. The engineer, upon completion of the levee, should leave careful directions with the land-owners as to its proper care and maintenance. A little constant watchfulness and necessary small repairs are better than yearly inspection, by which time extensive

and costly repairs may be demanded. In times of flood it is advisable to establish a patrol along the entire length of the levee. Protection of the slopes against the action of the currents and waves during flood periods is essential. A thick growth of small trees along the foreshore are an excellent protection. Where there is no such natural growth, willows, cottonwoods, etc., may be planted, but never nearer than 25 feet to the slope because of danger from penetration of the roots into the base of the levee. Another precaution essential to the preservation of the slopes is the securing as soon as possible of a good growth of tough sod over them, which is very effective in preventing erosion from rain storms or water action. No rank vegetation should be allowed, as it not only affords burrowing animals security from hunters, but the growth of bush roots, and growth and decay of weeds, loosens the soil and renders it more susceptible to erosion. A mowing-machine can easily be used on a 3 to 1 slope and possibly even on a 2 to 1. Pasturing the levee is

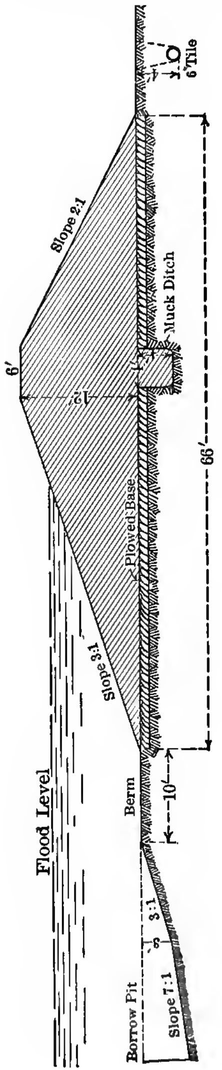

FIG. 54.—CROSS-SECTION OF RIVER LEVEE.

an effectual way of keeping the vegetation cropped, but care is necessary to prevent damage by the tramping of the live stock. Burrowing animals are a constant menace to the integrity of levees, the muskrat being especially injurious because of his habit of beginning his burrow under the water surface and continuing it up and across the embankment a foot or two below the surface. A permanent protection for the slope on the river side, in the shape of a revetment of rock 6 to 10 inches in depth is sometimes constructed, but this is expensive and is required only in places particularly exposed to running water or to waves.

The use of the top of a levee as a wagon-road is not to be recommended. A road following the levee, if one is desired, should be on the level ground just inside of the toe of the inner slope, or on a banquet on the inner slope. A railroad on top of a properly constructed levee is not open to the objections that are held against a wagon-road, as there is no cutting into ruts or displacing of the crown. A railroad embankment should not, however, be made to form any part of a protective levee unless especially constructed for that purpose.

Interior Drainage. The arrangement and size of the interior ditches merit the most careful consideration in levee districts for the reason that storage capacity is an essential factor in such drainage. If either pumping, or the periodic operation of sluices is relied upon, the ditches, and the soil also, must be capable of retaining a large volume of water and of delivering it constantly and uniformly to the pumps or to the sluices. To accomplish this end the main ditches must be large and deep, 7 feet, if possible, and nearly level in grade, a fall of 3 inches per mile being sufficient. If open ditches are employed entirely, about one acre in twenty, or possibly in thirty, will be required for main and field

ditches. These ditches must be kept in such condition that water will flow freely from every part of the system whenever its level is reduced by its escape through sluices or by the pumps. If the land is thoroughly tile-drained, the reservoir capacity of the soil is increased and a favorable condition for the economical drainage of the district is created. Where tile are liberally used, many small ditches that otherwise would be required can be omitted. Efficient drainage by pumps requires that the drains be designed to deliver the water slowly but continuously, and that they be kept in such perfect condition that they will deliver the water as fast as the pumps can remove it. If possible, all runoff from the adjoining hill country should be diverted and carried by gravity to the stream so that only direct rainfall and seepage need be removed by the pumps.

Sluices. Outlets for the interior drainage of districts protected by levees where gravity drainage is possible may be provided by sluices extending through the levee and equipped with automatic gates which close when the water rises outside the levee and open when it recedes. Sluices may be depended upon in cases where the water of the stream rises quickly and recedes rapidly, the water preventing the discharge of the sluices for a few days only, not exceeding a week. Under such conditions the levees prevent the overflow of the land, during which time the interior ditches and the soil retain the water without injury until the stream recedes sufficiently to permit the discharge of the accumulated water. The thoroughness of such drainage is dependent upon the length of the storm periods and the amount of precipitation on the land protected and also upon the entire watershed of the stream. The data most essential to the engineer in determining the efficiency of the gate system are the number of days in suc-

cession during which the gates will be inoperative, and the frequency of such periods. If these exceed 5 days a pump should be established to assist the sluices.

In designing the size of the sluice, the same coefficient should be used as would be employed for the gravity drainage of that section. The amount of head will, of course, depend upon the relative height of water inside and outside the levee. It will be safe, however, under ordinary conditions, to assume the velocity of the water through sluices to be 5 feet per second. In many cases the location will be such that the velocity will be much greater than this. The engineer should make careful computations of the capacity required, especially where no pumps are used. Unless the sluices are small enough to permit the use of iron pipes, concrete structures should be used.

Sluice Gates. Each sluice should be furnished with an outward-swinging iron gate at the river end, and also a sliding hand-operated gate at the inner end. The latter is required in case the operation of the swinging gate is prevented by débris from the stream, which not infrequently occurs. It is also sometimes desirable to retain a part of the water in the fields during drought, which can be done by shutting down the inner gate. Both ends should be protected with strong concrete bulkheads, and cutoff walls should be placed around the pipe or concrete conduit at intervals of 20 feet throughout its length to prevent seepage along its exterior surface. The end bulkheads must be made with special care, the walls not less than three feet thick, and with foundations 4 feet below the bottom of the invert of the conduit. The outlet end should be placed at low-water mark, if practicable, and the earth about the discharging point should be paved with riprap.

Diversion-Ditches. One of the serious problems con-

nected with the protection of lands which border hill or bluff lands is the control of hill water. Where it is gathered by natural streams that carry it direct to the river, it is necessary to construct what are called "return levees" along such tributaries to prevent their

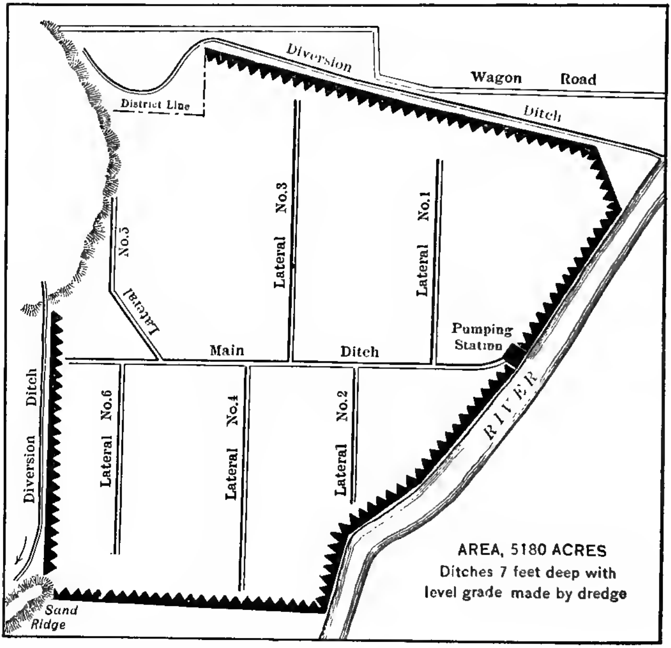

FIG. 55.—MAP OF AN ILLINOIS LEVEE DISTRICT.
Bulletin 158, U. S. Department of Agriculture.

flood-flow from spreading over the adjacent bottom land. It is also often necessary to improve the natural channels of such streams so that silt which they carry from the hills will not be deposited before it reaches the river. Intercepting and diversion-ditches are not infrequently required at the foot of the slopes on the

upper side of the district to prevent an undue amount of water from reaching the protected land, for all drainage that can be diverted and disposed of by gravity will lessen the first cost of the pumping plant, and the annual expense of operating it. Such diversion-ditches sometimes fill with silt from the hills and become useless, unless a receiving and settling basin is made at the foot of the slope. By taking advantage of the topography, a tract of 5 to 20 acres, or even larger, can be enclosed by a levee in such a manner as to receive the water from the hill stream where the bulk of the silt will be dropped and the water flow off through the outlet provided.

This method of preventing injury to channels by silt is being successfully employed in some localities. The basins, of course, will in time be filled and become land of great fertility. Arrangements must then be made to use some other land near by for a basin. If proper care is exercised by the owners of the hill land, much of the discharge of water upon the low lands can be checked. (See **Chap. XXI.**) A map of a representative Levee and Drainage District is given in **Fig. 55**, showing the protection of river bottom-land. Besides the main levee, the return levees at each end, diversion-ditches and interior open-ditch system are indicated.

Drainage by Pumps. Where the enclosed land is so far below the river or tide at their various stages that gravity drainage is impracticable, pumping plants must be installed to lift the water over the levee. In many localities land has become sufficiently valuable to warrant the expense, so that drainage by pumps is destined to become prominent in future reclamation work in this country.

Location of the Pumping Station. The station should be located where the water of the district can be brought

to it most conveniently and where it can be most easily discharged. Usually the lower or down-stream end of the district is the most favorable point. Consideration should also be given to other features, such as security of foundation, accessibility of fuel supply, etc., for the plant is a permanent part of the drainage equipment which must be maintained for all time and operated during a part of each year.

The plant should have:

1. A well-constructed gravity sluice with gates, such as have been previously described, should be built through the levee near the plant for the purpose of relieving the pumps of all water that can be discharged by gravity. The opening in the sluice should be low enough so that the highest point will be the level at which it is desired to maintain the water in the district. The entrance end of the pipe should be rounded to reduce entrance friction. The discharge end should have an automatic flap gate.

2. A suction bay deep enough to permit the suction end of the pipe to be covered when the water in the supply canal is at low stage. The bay should be protected by a screen fence to prevent débris from being drawn into the pump.

3. A discharge bay which will allow the discharge end of the pipe to be submerged at the pumping stage of the district.

4. A pile foundation on which to erect the building and the machine which it is built to contain.

5. At some suitable point a comfortable dwelling should be built for the use of the manager of the plant. Ample provision should also be made for the storage of coal.

Type of Pump. The centrifugal pump is the kind best adapted to drainage. It is simple in construction,

takes but little space, and can be obtained in all sizes. The size is usually given as the diameter of the discharge pipe. Pumps are made with both vertical and horizontal shafts. The larger pumps are usually of the horizontal shaft type and those larger than 24 inches are made with double suction which has the advantage of balancing the side thrust on the impeller and shaft. In order to reduce the entrance friction and discharge velocity, the ends of the pipes are enlarged and made bell shaped.

Steam is most commonly used for power, but gas or oil engines and electric motors are also successfully utilized. Where soft coal is abundant no more satisfactory or cheaper power than steam can be obtained. Electricity is more convenient, and where current can be obtained at a reasonable cost, small plants can be operated to advantage with that power.

To Determine the Size of a Pump. The capacity of a pump is usually computed by assuming the water to have a velocity of 10 feet per second, as for example, the capacity of a pump with a 24-inch discharge (a 24-inch pump) would be the area $3.14 \times 10 = 31.4$ cu. ft. per sec.; a 36-inch pump $= 7.16 \times 10 = 71$ cu. ft. per sec. If we wish to drain a district of 5,000 acres, using a drainage coefficient of ½ inch, the volume to be removed per second would be $5000 \times .021 = 105$ cu. ft. per sec. A 30-inch pump would be rated at 49 cu. ft. per sec. and a 32-inch at 56 cu. ft. per sec., the two making 105 cu. ft. per sec., the required capacity. If a coefficient of ¼ inch were used, one 56-inch pump would give the theoretical capacity. In all districts, however, not less than two pumps should be installed; both to be operated when the maximum capacity is required, but only one when the minimum and ordinary drainage is needed. Since this type of

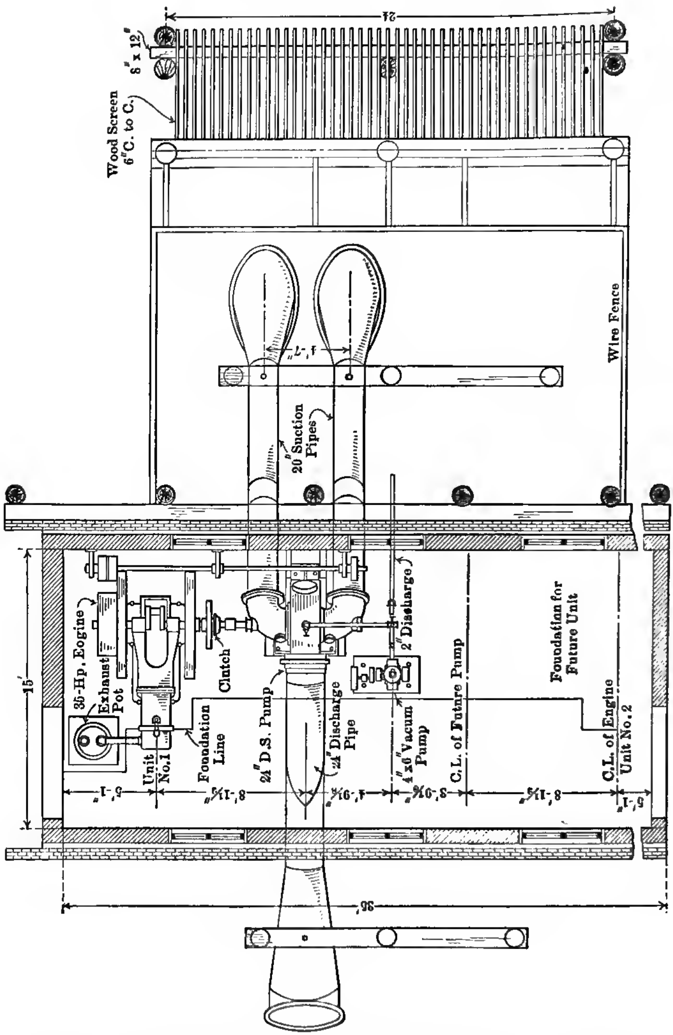

FIG. 56.—PLAN SHOWING THE ARRANGEMENT OF THE PARTS OF A DRAINAGE PUMPING PLANT.

pumps so often fails to show, upon test, the rated capacity, they should be purchased under the guarantee of the manufacturer, subject to a test after they are installed.

Horsepower Required. To find the horsepower required to operate a pump when the head and volume to be discharged are known, use the following formula:

$$\text{H. P.} = \frac{\text{Lift in ft.} \times \text{cu. ft. per sec. required} \times 62.5}{550}$$

Example. Required to remove 200 cu. ft. per sec. from a district with a maximum lift of 16 ft. What horsepower will be required?

$$\text{H. P.} = \frac{16 \times 200 \times 62.5}{550} = 363$$

Since the efficiency of an engine is approximately 70 per cent of the theoretical rating the actual brake horsepower required would be

$$\frac{363}{.70} = 518$$

The capacity of pumps is usually expressed by manufacturers in gallons per minute. To find the theoretical horsepower of a pump so rated we have

$$\text{H. P.} = \frac{\text{Gallons per minute} \times \text{head in feet} \times 8.33}{3300}$$

To this must be added a certain amount according to the efficiency of the plant.

The essential parts of a plant and their arrangement are well illustrated in Figures 56* and 57* which show the plan and elevation of a fairly typical drainage pumping plant.

Drainage Coefficient. The rate at which the pumps will be required to remove the water from the land will

*From a professional paper by Prof. W. B. Gregory.

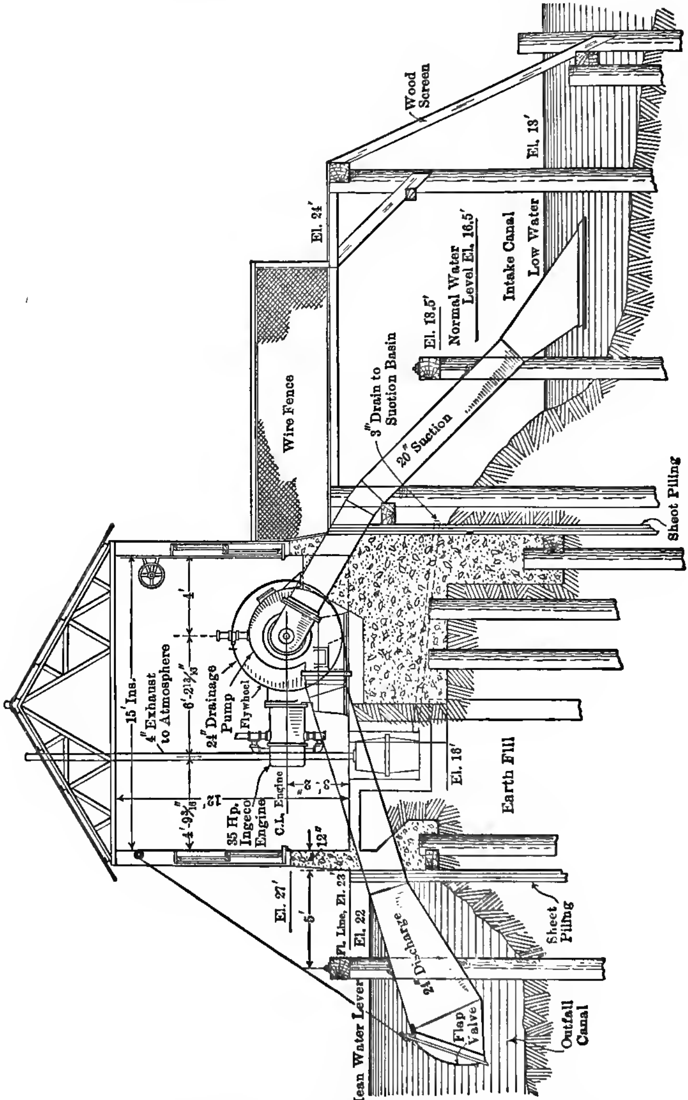

FIG. 57.—ELEVATION SHOWING ESSENTIAL PARTS OF A DRAINAGE PUMPING PLANT.

depend somewhat upon the size, arrangement, and grade of the interior ditches. If the arrangement and grade of the ditches are such as to lead the water to the pump rapidly the land near the outlet will be flooded unless the pump has a large capacity. On the other hand, if the water is held back through lack of ditch capacity or by the bad condition of the channels, the land will remain wet notwithstanding the ample capacity of the plant. Ditches in a pumping district should be large to afford storage and reservoir capacity to the end that the pump may be operated without frequent stops to permit the water to accumulate in sufficient quantity to supply the pump. In the upper Mississippi Valley a drainage coefficient of .25 to .3 inch is used in the design of plants though the tendency is to provide an auxiliary pump which will make the combined capacity about .5 inch, particularly where outside water passes through the district. It is found practicable on Louisiana cane plantations to remove as much as one inch in depth of water in twenty-four hours for a short time. In that section it is considered good design to make the ditches of the district with a capacity of .5 inch in depth over the land drained, and the pumping plants with maximum capacity of 1.25 inch in depth over the district in twenty-four hours.

CHAPTER XVIII

RECLAMATION OF TIDAL LANDS

MANY small areas of tidal marsh-lands within easy reach of large cities present attractive reclamation propositions. The inherent fertility of their soil, their exemption from protracted droughts, the demand for all products that can be grown upon them and the increased healthfulness which their drainage will insure to people who reside in their vicinity, give an importance to their reclamation which should not be overlooked. It cannot be denied that many attempts to reclaim tidal lands have failed at the outset or ultimately proved unprofitable. For this reason, the engineer should give the subject the most careful consideration from an agricultural as well as an engineering standpoint before undertaking reclamations of this class.

The results of a thorough examination of the subject are contained in "Tidal Marshes and their Reclamation," Bulletin No. 240 of the U. S. Department of Agriculture, by Geo. M. Warren, drainage engineer, under the direction of the author of this book, from which the following discussion has been for the most part taken.

Causes of Failure. Reclamation of this character is a form of levee districts in which the work is adapted to coastal lands and tidal conditions. From an extended examination of such projects it appears that the following are the principal causes of failure:

Lack of cooperation among landowners;

Ignorance or disregard of the fact that many marshes

when drained will settle or shrink to such an extent that gravity drainage becomes insufficient and pumping must be resorted to;

Levees of insufficient height, badly constructed, and poorly protected and maintained;

Sluices of insufficient size and of such poor mechanical construction that leakage back to the land greatly diminishes the amount of drainage that would otherwise be afforded;

Ditches so silted and choked with vegetation that adequate drainage of the land is impossible.

Relation of Water-Table to Vegetation. Upon salt marshes proper, depending upon the height to which they have been built up, are found various sedges, joint-grass, salt grass, and black grass. On brackish marshes are found three-cornered sedge, snip-snap, cattails, cord-grass, wild oats and red fescue. On reclaimed marshes where the ditch water rises to such a height as to frequently submerge and keep the lands saturated, reeds, cattails, and flags will flourish. Land which is occasionally submerged and but a few inches above the water-table produces the three-cornered sedge in great abundance. Little of value is obtained from land less than one foot above the water-table. At a slightly higher elevation, 1 to 1½ feet above the water-table, June grass and other native grasses come in, and with white clover or fescue afford excellent pasturage. If sluices and ditches can maintain the water-table within 6 inches above mean low-water outside, and this usually should be possible, it is safe to conclude that land situated 1½ to 2 feet above mean low tide would make good pasturage; 2 to 2½ feet above, good hay and corn-fields; and 4 to 4½ feet above, good wheat fields. Conservative forecasts on the crop production of such lands under good management would be 2 tons of hay, 65

bushels of corn, and 20 to 25 bushels of wheat to the acre. The reclaimed marshes along the Delaware and New Jersey coast produce grasses on damp lands, and corn, timothy, rye, oats, buckwheat, potatoes, strawberries, celery, melons, asparagus, and onions on the well-drained portions.

Where fresh water is available and can be promptly removed, much of the saline matter can be washed out of the soil. The usual method of subduing a rank sod is by burning, and this is to be recommended despite criticisms which have been made. If the burning does not extend deeper than 1 foot, the ashes and charred matter improve the texture of the soil, correct its sour condition by chemical action and promote nitrification.

Marshes with a deep soil which contains sufficient clay to render it somewhat slippery under foot when moist, are most likely to prove agriculturally profitable, and to be subject to only moderate settlement, as well as best adapted to the building and sustaining of levees, sluices and excavation of ditches. They are generally sour, and after draining, lime should be applied.

Shrinkage of Marsh Soils. Marsh soils shrink when deprived of their water. Experience both in this country and abroad has shown that where marshes have been drained there is a long continued shrinkage of the land, the amount of which varies with the character of the soil, being more in those of a peaty nature and less in clay, silt and sand. Approximate subsidences noted in several reclamations are as follows: Green Harbor, Mass., 1872 to 1908, about 2 feet; Hackensack Meadows, N. J., 1869 to 1887, 3 to 3½ feet; Cohansey Creek, Cumberland County, N. J., 2½ to 3 feet; Salem, N. J., 3½ to 4½ feet; Whittlesey, England, 7 feet in 18 years. Failure to discern the shrinkage in marsh soils has caused many to believe

that the tides rise higher than in former years, but there is no evidence that such is the case.

Dikes. The general method of constructing dikes, or levees, has been described in the preceding chapter. Some additional suggestions should be noted since those required to protect the land under consideration must withstand the constant action of the waves and tides of the sea, instead of the waters of streams which overflow their banks periodically, as is the case along rivers.

They should usually be located upon the most stable land and, if possible, 100 feet or more from the shore. Where not well protected by a wide foreshore, the outer slope of the levee must be flatter than 3 to 1, depending, however, upon its exposure to the waves and the material of which it is built. Where waves come directly against the levee, artificial protection is indispensable. This may be riprap or paving with large stones. It has been suggested that concrete blocks 3 feet square and 6 inches thick will form a durable revetment, and one cheaper than stone.

Capacity of Ditches Required. There is probably very little tidal marsh in the United States so high or so favorably situated that successful gravity drainage will not ultimately call into requisition every artifice of the engineer in reducing the ditch water to the lowest possible level. It is necessary that storm water and seepage should be intercepted by the ditches and delivered promptly to the sluice, and that there should be adequate storage capacity to hold the undischarged drainage at times of excessive precipitation or intermittent sluice action by reason of continued high tides.

To accomplish these ends there must be large storage facilities as near the sluice as possible, and the more distant lateral ditches should be designed as carriers rather than storage ditches. This arrangement places

the accumulated drainage where it is discharged quickly, the head necessary to move water to the sluice being reduced to a minimum and the discharge head of the sluice correspondingly increased. The small lateral ditches then become real drains and continue their flow toward the reservoir or storage basin for a long time after the gates have closed.

All ditches should be designed to reduce the friction head to a minimum. They should be on direct lines, free from obstructions and vegetation. The quotient arising from dividing the cross-sectional area of flow by the wet perimeter, or rubbed surface, should be as near a maximum as possible. This condition is geometrically complied with when the form is semicircular and the flow line on the diameter. However, in practice, such form would be impracticable, and rectangular or trapezoidal sections are necessary. The most efficient width is twice the depth, but since velocities vary, not directly, but approximately as the square root of the depths, the efficiency is not materially lessened if the width is made three or four times the depth.

From a consideration of numerous marshes and a study of rainfall statistics covering both the Atlantic and Pacific coasts, it would seem that ditches and sluices capable of caring for the runoff of a 3-inch rainfall in 24 hours over the entire drainage area would be fulfilling the conditions of an adequate yet not too costly design. With such a rainfall, actual measurements of runoff, which are confirmed by the known pore space of marsh soils, show that provision must be made for the removal of three-fourths of an inch per day over the entire area. This runoff amounts to 2,722 cubic feet per acre per day, but in view of the occasional failures of sluices to play, it is a reasonable and necessary assumption that storage should be provided in the ditches for

all of this amount. It will also be assumed that the ditch water should not rise higher than 1 foot above mean low water, and that at the end of sluice play it will be lowered to within 1 inch of the outside water.

On these premises the ditch area for each acre of land will be 3,000 square feet, or, in other words, about 7 per cent of the land must be given up to ditches. Under an average head of 1 inch, each square foot of sluice opening will discharge 1.5 second-feet. In one and one-half hours, the period of time a sluice would play, with the assumed height of ditch water and a tidal range of 7 feet, this will amount to 8,100 cubic feet, or 16,200 cubic feet per day. Since each acre yields 2,722 cubic feet per day, it is seen that each square foot of sluice opening would care for but 6 acres. This would lead to sluices of extraordinary size, and it is highly probable that if built, little advantage would be gained, for the reason that the high tides which usually accompany a storm make sluice action very uncertain, if indeed it be not entirely eliminated. Since the drainage water is stored in the ditches, no harm can be done the land if two or three days, say five operations of the sluice, are required to discharge it, and therefore 1 square foot of sluice opening would protect 15 acres of land.

The following table has been prepared along the lines above indicated.

In view of the fact that slopes of ½ to 1, or as usually dug by dredge, will in a silt-clay soil soon flatten below the flow line to about 2 to 1, reducing the capacity and efficiency of the ditch, it is recommended that the bottom, as excavated, be made about 9 feet wider than the tabular widths. It will generally be found preferable in large reclamations to use several small sluice-ways, placed side by side, rather than one large sluice opening.

TABLE XVII

The Periods that Sluices Play, the Necessary Clear Openings of Sluices and the Minimum Bottom Widths of Main Ditches for Draining Marsh Lands *

Land Drained in Acres	MEAN RANGE OF TIDE IN FEET																	
	2		3		4		5		6		7		8		9		10	
	PERIOD SLUICE PLAYS IN HOURS AND MINUTES																	
	3-05		2-25		2-05		1-50		1-40		1-30		1-25		1-20		1-15	
	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.	Clear Opening of Sluice in Sq. Ft.	Bottom Width of Main Ditch in Ft.
25	.9	1	1.1	1	1.3	1	1.4	1	1.6	1	1.7	1	1.8	1	1.9	1	2.1	1
50	1.7	1	2.1	1	2.5	1	2.8	1	3.1	1	3.4	1	3.6	1	3.8	1	4.1	1
75	2.5	1	3.3	1	3.7	1	4.2	1	4.6	1	5.1	1	5.4	1	5.7	1	6.1	1
100	3.3	1	4.2	1	4.9	1	5.5	1	6.1	1	6.8	2	7.2	2	7.6	2	8.1	2
200	6.6	2	8.4	2	9.7	3	11.0	3	12.2	3	13.5	4	14.3	4	15.2	4	16.2	5
300	9.9	3	12.6	3	14.6	4	16.5	5	18.2	5	20.2	6	21.4	6	22.7	6	24.3	7
400	13.1	4	16.7	5	19.4	5	22.0	6	24.2	7	26.9	7	28.5	8	30.3	8	32.3	9
500	16.4	5	20.9	6	24.2	7	27.5	7	30.3	8	33.6	9	35.6	9	37.8	10	40.4	10
600	19.7	5	25.1	7	29.1	8	33.0	9	36.3	10	40.4	10	42.8	11	45.4	12	48.5	12
700	22.9	6	29.2	8	33.9	9	38.5	10	42.4	11	47.1	12	49.9	13	53.0	13	56.5	14
800	26.2	7	33.4	9	38.8	10	44.0	11	48.4	12	53.8	14	57.0	14	60.5	15	64.6	16
900	29.5	8	37.6	10	43.6	11	49.5	13	54.5	14	60.5	15	64.1	16	68.1	17	72.7	18
1000	32.7	9	41.7	11	48.4	12	55.0	14	60.5	15	67.2	17	71.2	18	75.6	19	80.7	20
1200	39.3	10	50.1	13	58.1	14	66.0	16	72.6	18	80.7	20	85.5	21	90.8	22	96.9	23
1400	45.8	12	58.4	15	67.8	17	77.0	19	84.7	21	94.1	23	99.7	24	105.9	25	113.0	27
1600	52.4	13	66.8	17	77.5	19	88.0	21	96.8	23	107.6	26	114.0	27	121.0	29	129.2	30
1800	58.9	15	75.1	19	87.2	21	99.0	24	108.9	26	121.0	29	128.2	30	136.1	32	145.3	34
2000	65.4	16	83.4	20	96.8	23	110.0	26	121.0	29	134.4	32	142.4	33	151.2	35	161.4	37
2500	81.8	20	104.3	25	121.0	29	137.5	32	151.3	35	168.0	39	178.0	41	189.0	43	201.8	46
3000	98.1	24	125.1	30	145.2	34	165.0	38	181.5	42	201.6	46	213.6	49	226.8	51	242.1	55
3500	114.5	27	146.0	34	169.4	39	192.5	44	211.8	48	235.2	53	249.2	56	264.6	60	282.5	64
4000	130.8	31	166.8	39	193.6	44	220.0	50	242.0	55	268.8	60	284.8	65	302.4	68	322.8	72

* Prepared by George M. Warren, Drainage Investigations, U. S. Department of Agriculture.

Construction of Sluices. Sluices should be built in the most substantial and workmanlike manner. In important works, and where suitable foundations can be secured, mass concrete has many advantages. Reenforced concrete, because of its lightness and ability to withstand tensional and torsional strains, is especially to be recommended. If timber is used, it should be antiseptically treated, preferably with creosote (dead oil of coal tar). Wood impregnated with zinc chlorid, corrosive sublimate, or copper sulphate will prove less satisfactory on account of the solubility of these compounds in water.

All hardware should be noncorrosive, preferably of bronze, brass, copper, or galvanized iron.

The gate and its seat demand special attention. The link-hinge allows the gate to adjust itself to the seat, which should have a rubber or other resilient lining or cushion. To protect the gate and seat from the gnawing of animals or meddling of passers-by, it is recommended that it be set within a chamber or large manhole near the center line of the levee and both the outer and inner ends of the sluice be covered with suitable metallic bar screens. This position and protection of the gate would also insure its exemption from obstruction and interference by floating dêbris and ice.

To obviate cofferdam work, with the attendant expense, when renewals or repairs on the gate are made, it is suggested that each end of the sluice be fitted with two or more permanent vertical grooves, or guides, so that stop planks may be tightly placed over the ends, and the imprisoned water inside the sluice pumped out through the chamber, or manhole, which should be surmounted with a suitable wooden or iron cover equipped with padlock.

Not less than two "cut-off" lines of strong-tongued

and grooved sheet piling should be driven under the sluice and carried well into the levee on both sides to prevent seepage or "blow outs" under or along the sides. The weakest point in a levee is apt to be at the sluice, but if the sheet piling is driven deeply into the mud or to an impervious stratum, little apprehension need be felt.

For the purpose of counterbalancing heavy gates that they may swing under slight pressure, several devices have been employed, but there is probably none in use which is not open to more or less objection. Complete submergence of the gates greatly lessens the need of any counterbalancing mechanism. Gates of the "barn door" or "canal lock" pattern have been extensively used abroad, and to some extent in this country. They are best adapted to tidal streams draining large areas and where it might be desirable to pass small boats. The closing of these gates by the rising tide is liable to be accompanied by so much shock as to damage the gate or fastenings. They are believed to be growing in disfavor in this country and unsuited to the conditions of our present comparatively small reclamations.

Since sluices are one of the most essential structures used in tidal land reclamation, it will be well for the engineer to become conversant with the following facts which have been learned by experience and are set forth in the bulletin quoted.

A sluice will play longer for a given height of interior water the less the range of tide.

The length of time a sluice will play is governed almost exclusively by the behavior of the tide and by the relative elevations of the outer and inner waters. On the ebb-tide the gate will open when the water without passes the level of that within, and will remain open

until the succeeding flood tide rises to the level of the interior water.

The coefficient of discharge of sluices having unweighted wooden flap-gates in complete submergence is 0.64. Heavily weighted and poorly constructed gates may cause the coefficient to drop as low as 0.10 or even less. Light gates with long radius of swing, good mechanical construction and complete submergence are all favorable to a high coefficient of discharge.

In the examination of a considerable number of gates in operation, sluice leakage was found to exist to an unexpected extent. The smallest measured was 23 percent, and the largest 97 percent of all the water discharged.

The practice of making the sluices too small and setting them too high is general.

The relative merits of the so-called "high sluice" and "low sluice" have been discussed wherever gates are used. The advantage is distinctly with the latter. Only in the case of an exceptionally high marsh and large tidal range should the top of the sluice be placed above ordinary low-water mark. The advantages of the low sluice are:

It will discharge more water;

Its life, if of wooden construction, is immeasurably increased by reason of being always submerged, and not exposed alternately to the action of air and water;

Its effectiveness will not be diminished by any ordinary settlement or shrinkage of the marsh;

There is less liability of obstruction and clogging of the gates from floating sticks, reeds, and other débris, which on flood tide move toward the shore;

It is less liable to injury or interference in its workings by the action of ice.

The advantages of the high sluice are that it is less

expensive to construct and more easily inspected and repaired.

Illustrative Plan. Fig. 58 shows a fairly typical plan of a tidal drainage district on the west side of the Dela-

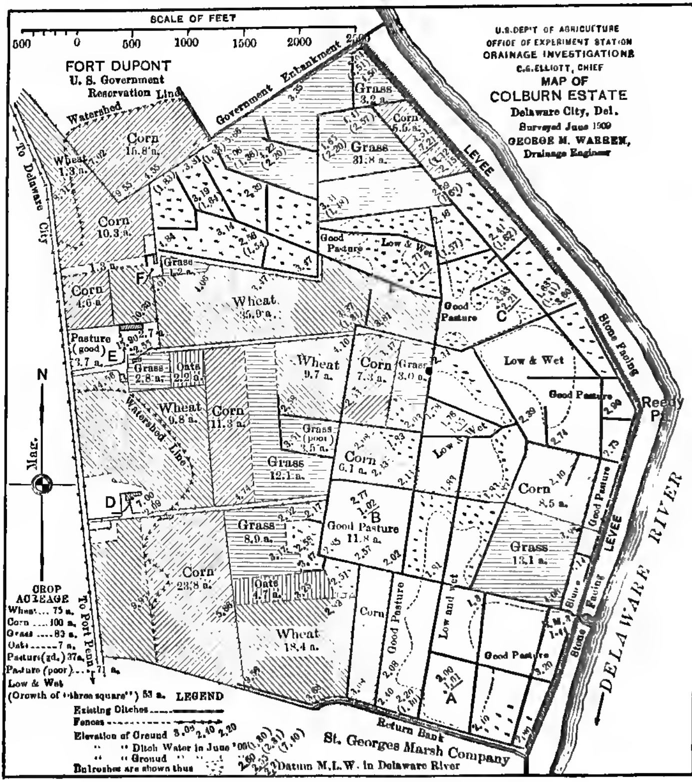

FIG. 58.—TIDAL MARSH RECLAMATION.

ware River which has been in cultivation for more than fifty years. The mean range of tide is 5.9 feet, the rise occupying 5⅔ hours and the fall 6¾ hours. The top of the levee is 9 to 11 feet above mean low water, but oc-

casionally has been overtopped. The tributary drainage area is 488 acres, and 11.4 miles of open ditches, varying in width from 3 to 24 feet and in depth from 6 inches to 4 feet, accomplish the drainage, and occupy about 5.3 per cent of the surface of the marsh land. The area of the sluice opening is 12.1 square feet or 1 square foot to 40 acres. This is insufficient to properly drain the land at times of heavy rainfall or adverse winds. The ditches are badly silted and choked so that their operation is too slow and storage capacity much reduced. The hydraulic gradient rises to 7 inches per mile, which is twice that required. The estimated cost of the levee, including the sluice, is about $6,900 per mile, and the reclamation of the marsh part alone has cost $54 per acre; based upon the whole drainage area, the cost is about $34 an acre. A fair return on the investment is being obtained.

CHAPTER XIX

DRAINAGE OF IRRIGATED LANDS

THE reclamation of arid land in the West, while contributing a large and valuable addition to our agricultural domain, has introduced a drainage problem of peculiar and significant interest to engineers and farmers in irrigated sections. Nearly every valley contains land that has been reclaimed at no little expense, which after being cultivated at a profit for a time has been abandoned or given up to crops of indifferent value because of its wet or alkalied condition. There are not less than a million acres of land in the States where irrigation is practiced which require drainage to make them profitably productive, and the constant increase in the acreage of irrigated land by government and private reclamation work is yearly adding lands which should be drained. Heretofore the tendency among farmers has been to wholly or partially abandon such lands and seek new fields, believing that the cost and difficulty of reclaiming did not, under the circumstances, warrant the attempt. With increasing demand for land this is no longer the case, and as a result, drainage districts from 5,000 to 80,000 acres in extent are being organized for the purpose of constructing suitable drainage outlets. It is seen that the lands must be restored, and that draining must be practiced in irrigated as well as in humid lands. These conditions open up a field for the investigation and practice of the engineer which will widen with the extension of irrigation and become more important as agriculture

in the irrigated States is further developed and perfected. Before the reclamation of such tracts is undertaken, the engineer should become conversant with the conditions which produce wet lands in rainless regions and the theory and practice of successfully draining them.

Conditions which Produce Seepage. Water for irrigation is obtained from some stream or reservoir and conducted by a canal along the upper side of a valley, and distributed by a system of lateral ditches to land which occupies a lower level. The canal and distributing ditches often pass through porous earth and lose a considerable amount of the water which is turned into them, while in other cases the waste from this source is apparently small. The application of the water to fields is always attended with a greater or less waste because of difficulty in so controlling the distribution as to supply the needs of crops without permitting a part of the water to escape into the subsoil. Where the soil is open this waste is sometimes one-half of the water applied, and where water is used with prodigality, a much greater amount finds its way into the subsoil. Some of this escapes later into streams or arroyos, but what remains as ground-water collects in the lower levels and after a time appears at the surface. This process goes on just as a basin or reservoir is filled from the bottom. No injury is manifest until the permanent water-table gets sufficiently near the surface to destroy crops either by wetness or alkali, and to make the land swampy. The supply of water to such locations during the irrigating season is constant, and hence the process of saturation is continuous. If the supply of surplus water is quite liberal, a swamp is formed in which cattail flags and tules grow luxuriantly.

Two structural characteristics of these soils modify

the behavior of irrigation water after it has been spread on the fields. The presence of sheets of hardpan which are of mineral composition, some kinds dissolving slowly in water, and others not at all, deflect soil water from its course downward, causing it sometimes to take a lateral direction and shoot out upon a sloping surface in copious amounts. Where the soil is underlaid with gravel the surplus water from irrigation flows readily through it down the slope until arrested by a loam which has less permeability. Here saturation to an injurious extent takes place and water rises to the surface, due to the pressure exerted upon it by that occupying a higher level.

Arid soils usually contain liberal quantities of salts which are soluble in water and harmful to plants when concentrated at the surface, as when water passes away by evaporation. Frequently the poisonous effect of the salts is the first intimation the cultivator has that the land has become too wet. The injurious salts most frequently encountered are sodium chloride, calcium chloride, sodium sulphate, magnesium sulphate, and sodium carbonate, some one or two of these usually predominating in a given locality. Sometimes swamping of the land occurs without injury from this source.

While the foregoing are the essential features of the occurrence, cause and condition of seeped irrigated land, a great variety of soils and numberless peculiarities will introduce differing factors into each problem when the engineer essays to apply the remedy of drainage in different localities. The general principles will be here discussed and local modifying influences must be considered as they present themselves in practice.

Preliminary Examination. It is first necessary to find the source of the water and where it enters the land which needs draining. Usually the wet condition of a

tract of land is not due to the water which is supplied to it by irrigation, but to that whose source will be found at some distance up the slope. It represents the accumulation of seepage which has percolated through the subsoil from higher land. The topography of the surface indicates the direction from which the water comes, but not necessarily the path which it traverses.

To determine this, a series of borings should be made with a two-inch auger, having a stem made of three-fourths inch gas-pipe in four-foot sections, which can be joined together by thimble couplings until a length of 12 feet is reached. A small steel rod is useful in sounding for gravel formations. By means of the auger, find the position of the water-table, and the depth to hard pan or to gravel, if they exist, beginning with the upper edge of the wet tract and sounding up the slope at intervals of 100 feet. It may also be well to dig some pits with a spade or post auger to ascertain the manner in which the water percolates through the soil. Elevations should be taken with the level at the points where borings are made, the record showing the surface, hardpan or gravel, if they are found, and water level. The relation of surface to the water-plane, and modifying agencies in the soil will be shown. These should be plotted, the elevations recorded, and the point or line where the water attacks the field located.

Fig. 59 is a map representing a survey of this kind, and showing the location of the drains which later were constructed and thoroughly drained the land. It will be observed that the depth to the shale was noted and recorded, and that the drains are located so as to intercept the water flowing from it. The depth of the ditches was about 6½ ft., with gravel relief-wells underneath them at numerous points.

In an examination, the depth of the source of water from the surface must be determined, for in one sense it is the key to the entire situation. All drains will be futile unless they in some manner reach the immediate source of the water and cut it off, both in volume and head. Examinations must be pursued until data sufficient to accomplish this have been secured. They should also cover the tract to be drained in such a way as to determine the character and depth of the saturated soil, and whether it contains hardpan, gravel, or other formations which will be factors in arranging the plan of drainage. The outlet for the drains need not be seriously considered until their necessary location has been ascertained, for it should be remembered that investigations are first made on the upper side of the tract with the view of finding the depth and location of a drain which will head all the supply of water that feeds the field. The importance of ascertaining the source of the water in order to properly locate the drain cannot be too strongly emphasized.

General Drainage Plans. Drains so located as to cut off the supply of seepage water are called intercepting drains, and with the accessories of small collecting wells to reach deeper supplies, and their connections with the main drain, form the Elkington system, previously described. (See **Chaps. II and VI.**)

Since the location of such an intercepting drain must depend upon the source and level of the seepage water, it may not be laid out in a straight line nor upon an even grade, the desideratum being the reaching of certain water points by it. As a rule, not many such drains are needed, if properly located, and as few as possible should be used. When the first drain fails to give the desired result it should be ascertained beyond doubt that it has been correctly located, before others

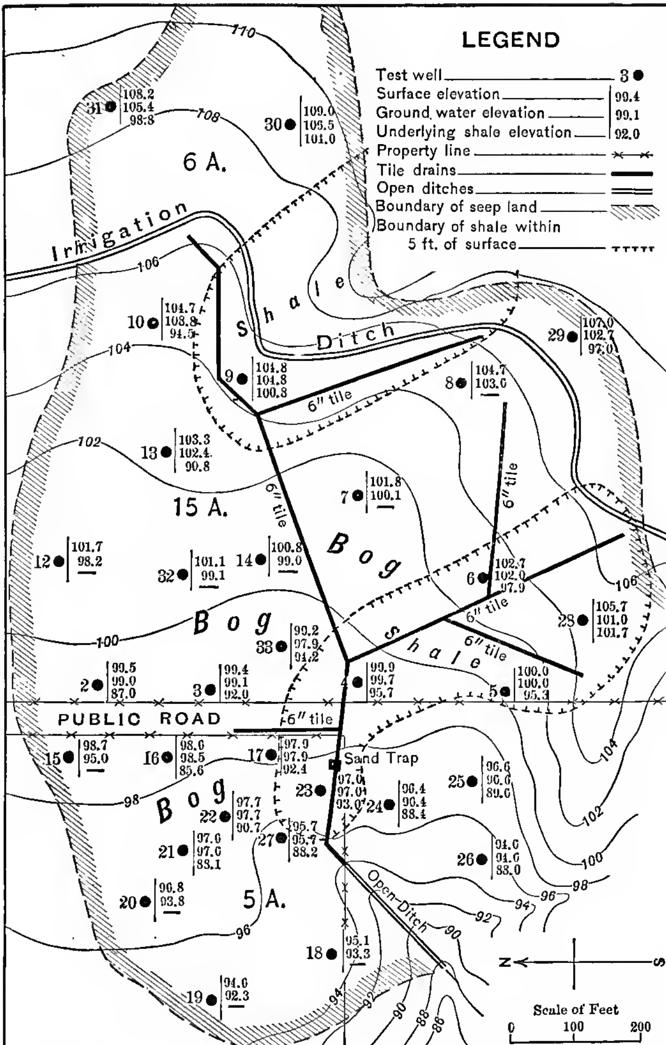

FIG. 59.—DRAINS ON IRRIGATED TRACT IN COLORADO.
Herman R. Elliott, Eng., Montrose, Colo.

are laid in a further attempt to carry away the injurious water.

On comparatively level or slightly sloping plains which require drainage, a few drains should be put in to prevent the accumulation of waste water due to irrigation direct, because all drainage which the land formerly had through the dry subsoil has been cut off. When large level tracts are to be treated, some attempt at uniformity of arrangement should be made, but the necessity of heading off the water by cross or intercepting drains should never be lost sight of. Little valleys, or draws, are sometimes found in a wet condition. Their slope and structure of soil is such that water has concentrated in them to the injury of that part of the field. A single drain will usually thoroughly restore such tracts to their former condition. The alkali flats in a field will suggest that drains be run through them, if proper attention has been given to intercepting the supply of underground water from outside sources.

Outlets. It is usually necessary to secure outlets by extending the drains to an arroyo, a "wash," or possibly to the river, but not infrequently the water may be discharged into an irrigation lateral, where the drainage water will serve to augment the irrigation supply. Such water is not usually charged with enough alkali to be detrimental to the irrigation supply when mingled with it.

There are, however, irrigated areas comprising many thousand acres, requiring drainage, for which artificial outlet ditches must be made by cooperation of landowners, who may invoke the aid of the State drainage laws for the purpose, as is done in the humid sections. The presence and operation of irrigation laterals make it necessary to carry irrigation water in flumes across

drainage ditches, thereby entailing some inconveniences which are peculiar to arid regions. Covered drains for outlets are to be particularly recommended wherever it is possible to use them, but where large districts are organized and require a common outlet, a few large open ditches will be necessary and provision should be made for maintaining as well as for constructing them.

Depth and Kind of Drains. Accumulation of soil alkali often accompanies seepage, and is due in a great

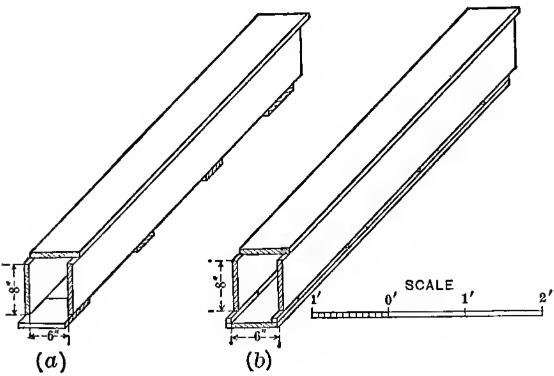

FIG. 60.—BOX DRAINS.

measure to the high capillary power of irrigated soils which acts by bringing alkali-bearing water to the surface, where it passes off by evaporation, leaving the salt upon or near the surface. The height to which water will rise and evaporate in large quantities is the minimum depth allowable for ground-water level. Generally a depth of 4 to 6 feet must be observed to satisfy these requirements, while depths of 6 to 8 feet are often needed to effectually intercept the underflow of seepage water.

Covered drains should always be used for fields and

for outlets, also, up to the limit of cost which can be borne by the landowners. Hard-burned, round drain-tile are preferable to all other material, but wooden boxes may be used with success where it is impracticable to get the better material. They are made of such size as are required, the simplest being constructed of boards 8 inches wide and one inch thick, as shown in **Fig. 60.** Such a drain is 6 x 8 inches on the inside. Where the ditch is in firm earth the bottom of the drain may be open, the sides being held in position by cross pieces as shown at **a** in the figure, but if the ditch is of a soft material the box should have a bottom with ½ in. lath blocks placed between it and the sides at intervals, leaving spaces to admit the water, as at **b.** They may be made in such lengths as will be convenient for laying.

Cement pipe are used, but in some instances have disintegrated under the action of alkali, and in the light of present information upon the subject cannot be unreservedly recommended. Sewer-pipe with cemented joints should be used where the drain crosses an irrigation lateral.

Capacity of Drains Required. The supply of water is due to a constant seepage during the irrigating season, the amount fluctuating with the frequency of irrigation and the amount of water applied upon the land at any one time. If the subsoil of the land supplying the water is gravelly, the amouht is greater and reaches the drain more quickly than where the soil is more dense. Not uncommonly the irrigation canals leak and contribute an indeterminate quantity of water to the soil. An estimate of this amount can be made only after a somewhat extended examination of the land during the irrigating season by means of borings. These examinations should cover the land lying between the

tract to be drained and the supply canals, for it is this land and not the area to be drained that should be considered in this estimate. Some irrigators apply many times more water than others, resulting, as might be expected, in a corresponding larger volume of drainage water. The quantity can be estimated with some degree of certainty by establishing small test wells at various points in the wet area and making weekly measurements of the rise of the water in the wells. The amount that should be removed by drains will be the amount of daily rise less the solid matter and the capillary water in the soil of the area under consideration. For example, if the water rises one-half inch in 24 hours over the entire tract, and the pore space is assumed to be 50 per cent of the volume of the soil, one-half of this being occupied by capillary water and the other half by drainage water, the depth to be removed by drainage will be one-fourth or 25 per cent of the entire rise, equal in the assumed case to 1/8 inch, or .0052 second-feet per acre or 3.36 second-feet per square mile.

The volume may increase or decrease materially for the same area owing to a possible extension of the limits of the irrigated land from which the water comes, or to a change in methods of irrigating that land which will affect the amount of water that finds its way to the seeped tract. The amount of drainage water to be taken care of depends upon the acreage of the higher land from which the water comes, and not of that which needs drainage. The capacity required of the main intercepting drain may be roughly approximated by estimating the underflow of the contributing area at from 1 1/2 to 5 second-feet per square mile, the former figure applying to moderately level plains of loam soil, and the latter to gravelly lands with considerable slope. Experience with these lands shows that the amount

of drainage is greater a year or two after the drains are installed.

Construction. The construction of drains in some kinds of saturated land is attended with much difficulty and expense, while in others the work is as easily performed as in humid regions. The method of preparing the bottom of the ditch for either tile or box is the same as before described for underdrains. Where soft spots are encountered, no better method has been found than to lay the tile upon long boards placed in the bottom of the ditch. It is often necessary to sheath and brace the sides of the trench to some extent while it is being opened and the tile laid.

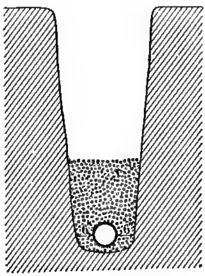

FIG. 61. — GRAVEL COVERING TO PREVENT ENTRANCE OF SILT.

Traction steam-trenching-machines are successfully used where the land is firm, but fail to operate in many soils where drainage is needed. Where they can be used they lessen the cost and expedite the work.

Gravel Covering. Much difficulty is experienced with sand entering the tile. The soil is frequently in a semi-liquid state, and during or soon after construction it is inclined to enter the joints of the drain, filling it more or less completely. Grass and weeds closely packed about the tile will frequently prevent this. Gravel, however, is much the best material for this purpose and should be obtained, if possible. When placed about the tile, as shown in Fig. 61, it forms a permanent filter which admits water, but prevents silt from entering the drains. All filling above the gravel covering should be compacted as closely as possible.

Sand-Traps. These are necessary in all but the most

compact soils, to collect the sand. (See **Chap. XI.**) They are also useful to admit water for occasional flushing of the drains when, on account of the light grades upon which they are laid, they become obstructed by silt. This is more apt to occur in irrigated land than elsewhere, because of the fineness of the particles of soil and the lack of cohesion among them in many localities where drainage is required. For this reason the engineer will do well to introduce sand-traps frequently in order to facilitate the maintenance as well as increase the efficiency of the drain.

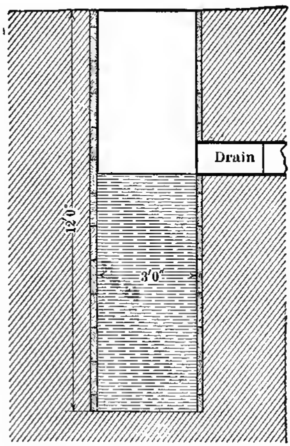

FIG. 62.—TWELVE-FOOT RELIEF-WELL, WITH TILE-DRAIN OUTLET.

Relief-Wells. It is not always possible to place drains deep enough to reach the supply of water that causes the saturation. Beds of water-bearing shale or of gravel which force water into the soil may be found eight or even twelve feet deep. Unless these supplies can be reached, drains will be of little service. The location of such strata should be found by the use of the steel sounding-rod and wells should be dug to the water-bearing formation. These should be boxed, or curbed, as shown in **Fig. 62**, and a tile inserted at convenient depth to remove the water as it rises in the well, or it may be a pit made directly beneath the drain and filled with gravel, as shown in **Fig. 63**. Such devices tap the supply of water beneath, and by relieving the pressure, permit the water which is under static head

to rise in the well and flow away through a drain placed at a convenient depth. These methods are successfully employed in draining soils underlaid with gravel, sandy loams and shale formations. In some instances a few wells placed outside the tract of wet land and discharging into a tile-drain will completely reclaim a large tract where any number of drains placed in the ordinary way would give no relief.

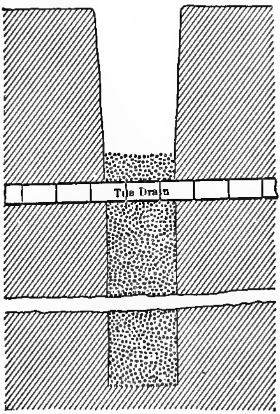

FIG. 63.—GRAVEL RELIEF-WELL UNDER TILE-DRAIN.

Removing Alkali. The results which follow the saturation of land are often serious by reason of the accumulation of injurious alkali, and these do not always disappear readily after drainage has been accomplished. While alkali is soluble in water and may be removed from the land by taking advantage of that property, the process is slow, requiring frequent irrigations, together with cultivation and continuous care. Copious flooding to dissolve the surface alkali and good drainage to remove the water that contains it, followed by cropping and continuous cultivation, are the means needed to complete the reclamation. This treatment distributes a part of the alkali through the soil as the water passes through, and removes a part with the drainage water. Surface drains often facilitate the work by quickly removing water heavily charged with alkali.

Timely drainage of irrigated lands will prevent all serious injury by alkali, but if neglected until salts

have accumulated in sufficient strength to completely destroy the crops, at least one season of continuous and careful treatment will be required to restore the soil to a productive state. It is a case where an ounce of prevention is worth many pounds of cure.

Reclamation of Irrigated Land by Dredged Open Ditches. An example of the drainage of a large area of water-logged and alkalied irrigated land by properly located and constructed dredged ditches is found in the Yakima Indian Reservation in the State of Washington, a map of which is shown in **Fig. 64.**

The land is a fine loam with a gravelly sub-soil which borings show to be from 5 feet to 8 feet below the surface. The effect of irrigation during a number of years was to water-log and render useless about 40,000 acres of land which during the first years of irrigation produced abundant and valuable crops. Later a part of the land became a veritable swamp.

The Reservation being under the control of the Bureau of Indian Affairs, an appropriation was made by Congress in 1910 for draining the lands. Borings and other examinations were made and from the information thus obtained ditches were located and constructed, as shown on the plan in **Fig. 64**,* the ditches being completed in 1912.

For a clearer understanding of the work it should be explained that the plan involved the construction of a main canal from the river westerly, parallel in a general way to Toppenish Creek for a distance of 20 miles. At 2-mile intervals lateral ditches were extended north for 1½ miles, at the end of which were head ditches that in the aggregate formed a continuous ditch with outlets into the cross laterals which in turn discharged into the main outlet canal. The upper ditch intercepts

*By James Wm. Martin, engineer in charge.

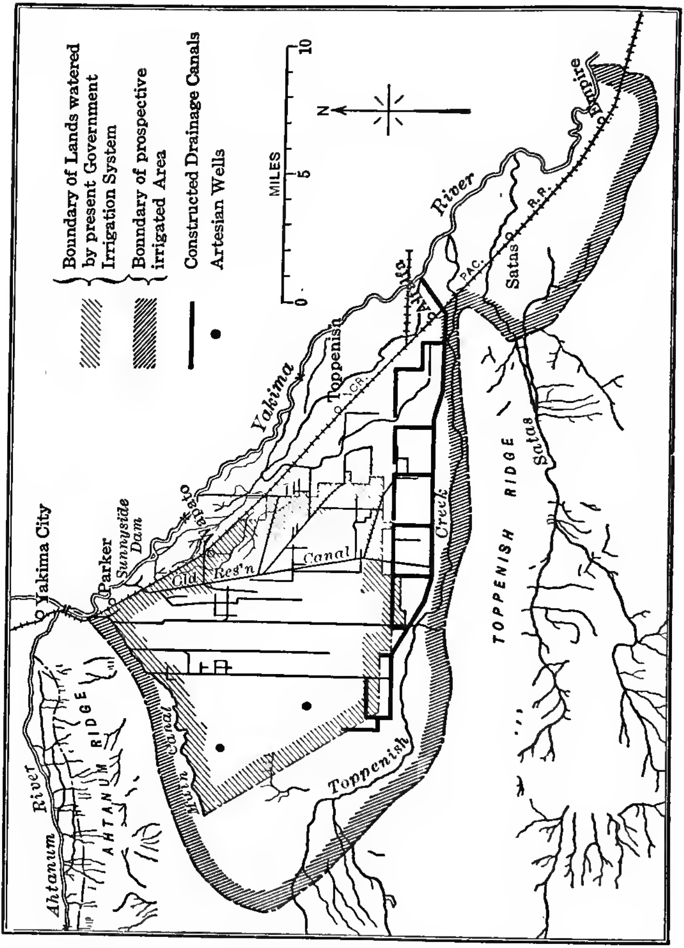

FIG. 64.—IRRIGATION AND DRAINAGE DITCHES ON THE YAKIMA INDIAN RESERVATION, STATE OF WASHINGTON.

the seepage from the land north of it. The two east and west ditches, with the cross canals, form a block of ditches which intercept all of the seepage and surplus irrigation and carries it direct to the river.

As a result of the work which was finished in 1912, the land between the main ditch and the creek is completely drained without additional ditches. Crops were grown on the land the year following the completion of the ditches without flooding for the removal of alkali, and the entire tract which had gradually deteriorated and had been finally ruined has been restored to its former productiveness by draining. At the completion of the ditches the discharge of water from the entire 40 miles of ditches through the main canal was 200 cu. ft. per sec.

The fact should be noted, however, that the soil being underlaid with gravel made the effect of the drains more marked and rapid than would be the case were the subsoil a clay. It should be further observed that land with a gravel subsoil, though adjoining a creek, did not have sufficient natural drainage to prevent water-logging, and the ruin of the land by seepage and alkali.

CHAPTER XX

DRAINAGE OF PEAT AND MUCK LANDS

THERE are several million acres of muck and peat lands in the United States, large bodies being found in Wisconsin, Minnesota, Maine and Florida, and small detached areas in various other parts of the country. They are distinguished from other soils by their loose structure and the large percent of organic matter which they contain. The difference between peat and muck consists principally in the degree of decomposition of the vegetable material composing them, and the amount of silt which may have found lodgment between their particles. Their fertility characteristics as well as their drainage properties place them in a class by themselves, and one requiring special consideration and treatment. It has been pointed out in foregoing chapters that intrinsic fertility should be first considered when drainage for agricultural use is under contemplation, and that the two should be investigated in connection with each other. It is but natural that these lands should have received tardy attention because of their less favored condition when compared with other soils, but they are now very properly attracting notice in common with wet lands of all kinds which are subject to reclamation by drainage.

It should be noted with reference to their origin that peat soils may be classed as "moss" peats and "grass" peats or muck, and that the materials of which they are formed are found in almost every stage of decomposition and density. To these differences and physical

peculiarities is probably due more conflicting experiences in draining such lands than those of any other class that can be named.

Peat Lands of Europe. The drainage and management of peat lands have occupied the attention of farmers and engineers in England, Scotland, Germany, Sweden, and other European countries for at least a hundred years. While the origin and composition of moss-peat in these different localities vary widely, their general characteristics with respect to drainage are quite similar. In the first place they have, in many instances, not responded to the ordinary methods of draining, and when by special treatment they were made dry, it was found that their subsequent need of moisture content was of no little moment, and methods of irrigation were of necessity devised. We learn from the experience of engineers with moss-lands in England and Sweden that they can be made too dry, in which state they are as valueless for production as when too wet. The remarkable yield of grasses reported from these drained lands after being irrigated show that their proper water content is a vital factor in their productiveness. It is quite possible that the need of irrigation has been lost sight of in later investigations, but all who are capable of giving an opinion upon the subject admit that these lands must first be well drained before they can be fitted for the production of valuable crops.

It is also noted, in a study of these marshes in various countries, that they are as frequently found resting upon sand as upon clay, and that there appears to be no material difference in the structure of the two or in their value after reclamation. Those underlaid with clay are drained with more difficulty, since the water must be removed from the marsh by means of frequent

and deeply laid underdrains. The clay bottom aids in retaining needed moisture and, where it can be reached, forms an excellent material for mixing with the peat, supplying, in a measure, it is claimed, the potash in which these lands are deficient.

Several million acres of peat, or "moor land," are found in Germany, where in recent years the Government has established stations for experimenting with their reclamation. The results show that they can be profitably reclaimed. As has been said, the first step in such reclamation is drainage. After preliminary open ditches have made the land somewhat firm, tile-drains, 65 feet apart and 40 inches deep, dry the land with sufficient thoroughness. In some localities stops are placed in the drains when the flow runs low, in such a manner as to hold the water-table within two feet of the surface; in others the supply of water from beneath is sufficient for all seasons.

Peat and Muck Lands in the United States. Turning to the peat and muck lands of our own country, we may say with reference to their productiveness, that while they require special treatment and skilful fertilizing, many of them are capable of producing profitable crops of a special character, these depending much upon the quality of the muck and the climate of the section in which they are found. The drainage problem connected with them is of vital importance, and, it may be added, the conservation of moisture as well. Experiments conducted in Indiana and Illinois by the State Experiment Stations, relating principally to fertility questions, show that fertilizers, particularly potash, are needed, but it is concluded here as elsewhere that before any system of improvement can be successful the soils must be well drained.

It is conceded that the treatment of muck lands

upon a clay foundation is more simple, as far as fertility is concerned, from the fact that the clay subsoil when mixed with the muck has a marked effect on its productiveness. An instance of this kind is cited, in which plowing the soil after drainage sufficiently deep to bring some of the clay subsoil to the surface, converted a comparatively barren soil into one which produced 60 bushels of corn to the acre. Clay is in some instances mixed with the muck soils of the fens of England by hand labor, with great advantage to the quality and quantity of the crop.

A general review of the production of peat lands indicates that they are particularly adapted to growing grasses, onions, celery, cabbages, potatoes, and root crops generally, and that they are more subject to both early and late frosts than other lands.

Drainage Coefficient. Experience in draining the lands under consideration seems to indicate that the maximum runoff to be provided for by main ditches should not be less than for loam soils in the same climate. When once dried out, they require much more water to fill them than any other cultivated lands, but when once filled, as they are during the rainy season, or when snow melts in the northern climates, the land requires as great ditch capacity as any other. Muck soils are easily injured by surplus water and require prompt drainage, though by reason of their porous nature fewer lateral drains are needed to lead the water to the main ditches.

Sand Subsoil. The lands are usually quite level, necessitating ditches with grades of one or two feet per mile. The underlying sand greatly facilitates the drainage so that open ditches are effective when the excavation is extended well into the sand. In northern Wisconsin, where the peat formation is often not more than

two or three feet deep, ditches which were formerly dug four and five feet deep are being increased to 7½ feet, in order to give more effective drainage to lands lying at some distance from them. Ditches of this depth placed one mile apart supplemented by farm ditches give fairly satisfactory drainage for farm crops.

With regard to the stability of side slopes of ditches, the top peat and underlying sand exhibit quite different characteristics, the former standing very well at a slope of ½ to 1, while the latter assumes a slope of about 2 to 1. It is found best to excavate the top part of the ditch with nearly vertical sides giving a flat slope and broad bottom to that part of the ditch excavated in the sand. In some areas where sand is found, for the most part at a depth of 3 or 4 feet, muck may be found as deep as the ditch is excavated. In such places the effect of the ditch laterally will be restricted to such a degree that lateral ditches must be inserted quite freely to secure uniform drainage.

Clay or Muck Subsoil. Where clay subsoil prevails, lateral tile-drains are required at intervals of about ten rods, in addition to the main ditches. These should be laid not less than four feet deep, where in either clay or muck they will remain in alignment and be permanent, since the ground at that depth will be wet and below the horizon at which settling takes place. If placed at a shallow depth where shrinkage is going on constantly, they will not be permanent.

Settling, or Shrinkage. This is a factor that must be taken into account throughout the reclamation and management of such land. The top turf is often burned off to a depth of one foot as a preliminary to subduing and cultivating the land. The remaining soil, when drained, begins at once to settle by reason

of the withdrawal of water from the large pore spaces which are a characteristic of such lands, and the decay of the fibrous vegetable matter of which the peat is composed. Three years after draining many peat soils have shrunken to one-half their original thickness. This statement applies especially to the shallow formations lying upon sand. At least 33 per cent of depth above the plane of the drains should be estimated for settling.

Another characteristic relating directly to the drainage properties of all soils containing a large per cent of organic matter is this: that as the soils become older they become more compact and require additional drains to keep them sufficiently dry. In view of this fact the primary lateral drains should be so arranged that others can be added as the necessity for them appears. This progressive method of draining is economical and effective if the probable requirements are anticipated from the first. This method should not, however, be applied to the main ditches. They should be made complete, and of the required size when first excavated.

Regulation of Water. While muck soils require efficient and thorough drainage, they also dry out rapidly and possess some properties pertaining to capillarity, retaining and giving up moisture to vegetation in a manner peculiar to themselves, and not yet well understood by scientists. The peculiar moisture changes through which these soils are continually passing cause variations in their agricultural value as well as an erratic behavior with reference to drainage. It may be safely said, however, that for some kinds of crops, devices for controlling the height of the soil water during dry seasons should be applied to lateral, and possibly in some instances to main ditches, in order to secure the

best results from the land. For general field crops, a method of compacting the soil by pulverizing it finely and rolling with heavy field roller has been found to greatly assist in retaining the moisture during the dry part of the season.

CHAPTER XXI

CONTROL OF HILL WATERS

THE need of conservation and control of rainfall as well as of removal of surplus water, has been emphasized in preceding pages. This is especially important upon agricultural lands with rolling surface or steep slopes. When unchecked by any device of the cultivator the rainfall in such localities is not only carried off the land before the soil can absorb enough to meet the needs of vegetation, but the flow of water is so rapid that it does great injury in its downward course. The cultivation of hill lands, especially when this is shallow, as is too often the case, leaves the surface in condition to be quickly saturated and moved down the slope. Small lengthwise depressions serve to concentrate the water into rivulets which rapidly increase in size, and extend their eroding and devastating effects with every successive storm. The water with its volume of soil in suspension passes swiftly toward the main drainage stream, leaving some of its load of earth on the bottom-lands as it passes over them, and deposits the remainder in the channel of the stream when the velocity of the latter is not sufficient to carry it along. The result is the almost irreparable injury to the hill lands and the raising of the beds of streams so that they periodically overflow and render the valuable level land along their course useless. This train of calamities, involving the depletion of cultivated hill lands and the ruin of the valleys for profitable farming purposes is recognized by all who are familiar with such situations, yet, as a

rule, only meager and ill-directed means are employed to obviate or mitigate these disastrous effects.

The finding of an adequate remedy for these unprofitable conditions merits the careful attention of the drainage engineer, even though it consists as largely in proper treatment and cultivation of the land continuously as in methods of drainage, but the latter play an important part in many localities.

Drainage by Proper Plowing. One of the fundamental principles of drainage should be recognized in the effort to control hillside waters, though the method of accomplishing it may not be commonly considered drainage. The principle referred to is that surplus water should be removed, as far as possible, through the soil instead of over it. Natural drainage on slopes tends to remove the water too quickly, not permitting its proper absorption by the soil. If in the cultivation of hill lands the plowing consists of deep furrows across the slope and with the contour, both the flow of the water is checked and the soil is made receptive to such a degree and depth that a liberal part of each rainfall passes from six to twelve inches beneath the surface, where it either remains as moisture for the supply of growing crops, or distributes itself gradually through the soil, the surplus finally appearing at the foot of the slope as seepage, which may be taken care of by drains, as described later.

Preventing Concentration of Water. It is readily seen that a method of cultivation should be adopted which will lessen the opportunities for the concentrating of the water and its formation into streams that sweep down the slope carrying soil and fertilizer with them. What is known as the level method of culture is adapted to this purpose, and should be used where heavy rains are liable to cut deep gullies in the slopes. Land

placed in grain or grass should first be evened on the surface in such a manner as to remove all existing gullies or so broaden them as to spread the water. This method prevents concentration of the water by facilitating its passage into the soil and causing it to pass over the surface in sheets rather than in narrow streams. Such treatment of slopes is very important and in many kinds of lands will entirely prevent soil washing, with the added benefit of making the land more drought-resistant.

Tile-Drains Needed. Where gullies persist in forming, despite all efforts to prevent them by proper treatment of the land, it will often be found that the erosion is caused by seepage at various points about midway between the crest and the base of the slope. Water which has run along a stratum of impervious subsoil oozes out upon the surface during the winter season to such an extent that spring rains quickly displace the softened soil at such points, and thus start a gully which concentrates the water and which is rapidly enlarged to serious proportions. The efficiency of a tile-drain laid directly through and across seep spots at a depth of about three feet has been satisfactorily proven, and such a drain should be constructed of 4-inch tile, and extended to the nearest available point of discharge. If small stones are placed in the ditch for a depth of several inches over the tile, the good effect of the drain is often increased.

Erosion may be arrested where gullies have formed, by properly preparing the bottom of each gully and laying tile-drains in them. Fill all the trenches and dress the surface by plowing until the gullies are leveled so that only broad, flat depressions remain. Surface-inlets of the gravel or stone pattern (See Chap. XI) should be put in near the upper end of such drains as receive

the accumulation of water from the upper part of the slope. These drains are especially valuable in meadows and pastures where the surface can be kept in sod, but may also prove of benefit in cultivated fields.

Level land at the base of hills may be protected from the hill water when necessary by an intercepting drain of 6-inch tile laid parallel to the foot of the slope and along the line where the greatest seepage appears. But it is much better when possible to begin the interception at the top of the hill by some or all of the methods mentioned for the protection of hill-sides, and when this is done, often the drain at the bottom will be unnecessary.

Level Terraces. The method of controlling the water by hillside ditches and terrace banks, once very common, is being superseded by the level terrace either cultivated or laid in grass, the object of this treatment being to distribute or spread the water over the surface instead of holding it back in concentrated form, as is the case in contour ditches and banks.

The method usually followed in laying off and building such terraces is to select a point about midway on the slope, and run the first line with the level, setting line stakes on a true contour, or on a light grade according to the plan adopted. Other terraces are then run in above and below this, spacing them 30 feet apart where the slope of the hill is steeper than 12 feet in 100 feet, and at a greater distance on the flatter slopes. After the line is marked, a wing plow drawn by four mules is employed in building the terrace. The first furrow is run on the lower side, throwing the earth up the hill on the line; this is continued around the upper side throwing the earth down hill onto the line. One more furrow is run above and below and the terrace is complete. These terraces not only check the flow of water

and spread it out, but also collect and retain the finer soil and fertilizers washed from above, so that in a few years the soil on and immediately above them becomes very rich. After the terrace banks have been allowed to stand about five years they are plowed up and new

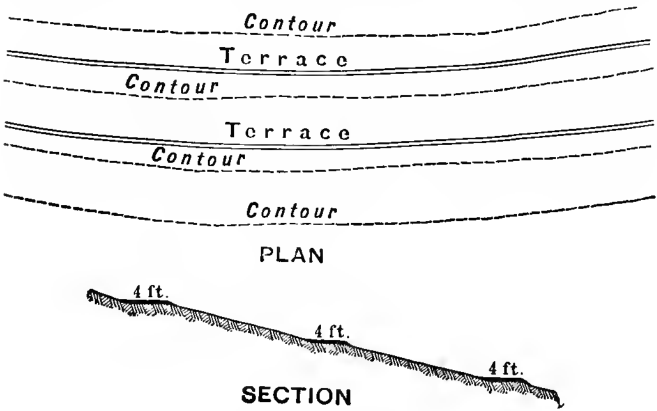

FIG. 65.—LEVEL TERRACE.

ones constructed midway between the old ones. This style of terrace is illustrated in **Fig. 65.**

The Mangum Terrace. It is probable that the form of terrace best adapted to the conservation of hillside water and soil is what is known as the "broad falling" or "Mangum" terrace. (**Fig. 66.**) As originated and constructed by Mr. P. H. Mangum on his farm near Wake Forest, N. C., it consists of a bank about 8 feet broad and 12 inches high, with a shallow ditch, or flat, 10 feet wide on the upper side, from which the material for the bank is secured. The terraces are constructed across the slope of the hillside with a fall of 1 inch per rod. In order to keep the terraces from becoming too long they are always run in the direction opposite to the

main drainage of the country. The vertical distance between them may vary, but is usually 3 to 3½ feet. The crop rows are run with a greater fall than the terraces and in the opposite direction, the amount of fall depending upon the slope of the ground. These are, therefore, at a small angle with the terraces, and are

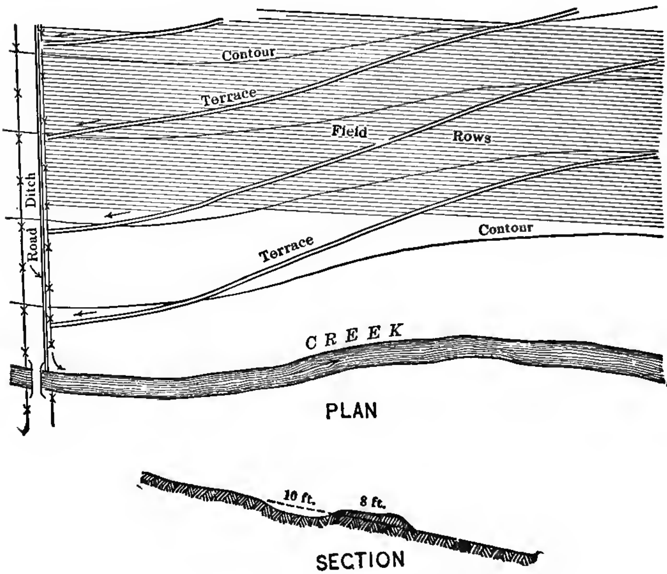

FIG. 66.—THE MANGUM TERRACE.

carried across them so that the entire field is cultivated. Outlets for the broad ditches are made at the most available points.

The theory of this terrace, which has proven true in years of practice, is that a broad shallow stream of water does not have as great velocity as a narrower and deeper one, and that by decreasing the velocity more water is taken up by the soil, and less soil and fertilizers

are washed away, or, in other words, concentration of water is prevented. This form of terrace is well adapted to all hillsides with the exception of those having slopes greater than 12 feet in 100. On these the banks would be too close to be economical, and the level terrace first described is the one to construct.

Junction of Hill Watercourses with Main Streams. Perhaps no fact connected with the flow of water charged with silt is better demonstrated than that such water will deposit its sediment wherever the velocity is seriously checked. The deposit of beds of soil by hill watercourses at the foot of the slope emphasizes the need of so connecting such channels with the main stream that the sediment will be distributed and carried on. The best method of doing this will depend upon the local conditions of soil, amount of slope, and depth of ditch that can be obtained. The plan that should be first considered is to open a ditch with uniform grade and of sufficient capacity from the foot of the slope to the bottom of the main channel in the most direct course. If the main stream has been put in good condition this method will be the proper one to pursue. In some cases a better way may be to deflect the hill stream from its direct course to one down the valley, thus taking advantage of its slope in securing a more uniform grade.

CHAPTER XXII

DRAINAGE OF HOME SURROUNDINGS

COMPARED with the extensive drainage projects which may occupy much of an engineer's time, the drainage of farmsteads and village lots seems insignificant, and hardly worth consideration. This is unquestionably true if such work is viewed with reference to its difficulty or to the time it occupies, but when results are taken into account, the drainage of the home surroundings is of great importance, not only from a sanitary standpoint, but because of the convenience and comfort insured, not to mention the larger yield from garden and orchard and the added beauty of the grounds by reason of better lawns and more vigorous growth of trees, shrubs and flowers.

The underdrainage of **lawns** and **residence grounds** should be governed by the same rules as that of land in general, care being taken to so locate the drains that they shall pass between trees and shrubs, as it is not desirable to have these directly over a tile-drain, as roots may enter and obstruct the drain.

Gardens require more thorough drainage, laterals of 4-inch tile laid 3½ feet deep and 40 feet apart, being needed.

Orchards are greatly benefited by underdrainage, and in those with clay soil or subsoil it is almost imperative. Not only is the yield increased but the quality of the fruit is superior where underdrains are employed. These should be of 4-inch tile, laid 4 feet deep between the rows of trees, connecting with a main at one side.

Cellar-Drains. A house should never be built on clay soil without having a tile-drain laid before its foundation walls are erected, a few inches below them, and so protected that the weight of the wall will not rest upon it. It should be of 4-inch tile with a grade of 3 inches per 100 feet, and connected with a main having a free outlet. If the house is already built, or if for any reason it is preferable to lay the drain just outside the wall, it will be equally effective, but placed below the wall it requires but little extra trenching. The important point in either case is that it shall entirely surround the house and be below the level of the cellar floor, that it may intercept all outside water. If the house is on a side hill, there may be spring or seepage water that will need intercepting above the house, to protect both cellar and yard. In such a location, examinations should be made to determine if this is the case.

Roof-Water. Where the rainfall upon any building is not conducted into a cistern, it should be removed by drains. The eaves-troughs and down-spouts on the house should be ample, which they frequently are not, and the latter should connect with a tile-drain not less than 6 inches in diameter, and for large buildings 8 inches, laid on a grade of 3 inches per 100 feet, 4 feet from the wall of the building, and from 3 to 4 feet deep. At the points of discharge an upright pipe of sufficient size, set close to the wall and extending 8 inches above the ground, should receive the ends of the down-spouts and connect with the drain by a curved tile and a Y junction. Such drains may, if desired, form part of a farm system without necessitating any increase of its capacity, as the roof-water will pass away before that from the soil enters the drains.

Stock-Yards. Underdrains in barn-yards and cattle-

pens laid without any accessories are of no value whatever, because of the puddled condition of the surface, due to the tramping of the stock. Surface-inlets are an absolute necessity in such places. These must be fenced or otherwise protected. A shallow, open ditch encircling a stock-yard just outside its limits, so graded as to carry off the water from surrounding land, will aid materially in keeping such a yard dry. Special care should be taken to carry the roof-water of adjacent buildings away through underdrains so that none will be discharged upon the yards. This precaution is often neglected, and is responsible for much of the unsightly and annoying condition of farm-yards.

Paddocks and pastures near the barn, particularly the parts that show their wet condition by a growth of inferior grasses, are profitably underdrained. Hillside erosion, which often occurs on rolling pasture lands, can be checked by placing drains in the gullies which have begun to form, and leveling the land over them. Intercepting drains along the foot of slopes will prevent too much wetness on the level area. Well-drained pastures are much more healthful for live-stock.

Village Drains. The reclamation of large level areas and swamps by means of canals and a general drainage system will result in establishing new towns and shipping points, which will have a prominent part in the development of the region. A neglect to thoroughly drain the site of such towns will result in much discomfort and loss. The value of such drainage to towns has been proven in the level lands of Illinois where, in many localities, every street and cellar is provided with tile-drains. These towns are notably sanitary, as is shown by health statistics.

Every town located in level sections should have a large tile outlet extending to the nearest drainage canal,

and lines of 8-inch tile laid in every street 20 feet from the nearest property line and about 4½ feet deep. This will serve to keep the street grade firm and to furnish an outlet for each cellar. These should be regarded as strictly soil-water drains, and should in no case be used for house sewers. When placed on every street, all yards and gardens can be drained as may be found necessary, and there will be no excuse for the existence of stagnant water, mosquitoes or malaria. Surface-inlets can be used to admit surface water at selected points. Silt-basins should be set at street corners and where branch drains enter. The town should have the engineer make a complete map and profile of every drain. A permanent bench-mark should be established to which all levels should be referred. In short, as much care should be taken in planning and recording the system as is exercised in developing and executing an expensive sewer-system.

Road Drainage. Road making is a subject so closely allied to land drainage that it should be included in a drainage engineer's course of study. Much has been written on the subject, and the engineer may become fully instructed in the important art of making durable highways. These are coming to be more and more appreciated and demanded throughout the country. No attempt will be made to take up the subject here other than to mention the underdraining of roads to secure a firm road-bed. This is done by laying a tile-drain at the toe of the road embankment about 3 feet below the surface-ditch on one side of the road, or if through very boggy soil it may be advisable to have a drain on each side. This depth will bring it about 4 feet below the level of the ground and 5 feet below the crown of the road. If for the use of the road only, and not connected with other drains, 5-inch tile will be suffi-

ciently large. If forming part of a farm system its size must be determined as for other drains. Where laid along private farm roads, 4-inch tile will be large enough.

Road culverts made of sewer pipe are often carelessly constructed and covered with insufficient earth to be lasting improvements. The joints should be well cemented and the ends at each side of the road should be encased in concrete abutments two feet thick and extending two feet below the flow line, while the pipe should be covered to a depth of not less than eighteen inches.

CHAPTER XXIII

ESTIMATES AND ACCOUNTS

THE ability to make correct estimates is a valuable asset to any engineer. To calculate approximately the cost of an enterprise requires a comprehensive knowledge of the character and amount of work contemplated, and the probable cost conditions under which it will be done. A further demand is made upon the drainage engineer in that he is also called upon to appraise the value of the benefits which are anticipated as a result of the work. It may be urged that the individual, syndicate or board of commissioners who are responsible for the financing of the improvement are the ones upon whom this devolves. While this is true in part, the engineer will find that he will be called upon for advice based upon the relation of profit to costs, and his duties should include a critical study of benefits and profits in connection with costs.

The engineer should not be a professional promoter, indulging in highly colored portrayals of the profits and advantages of the undertaking in hand, to the exclusion of all suggestion of unfavorable contingencies that may be met, nor should his representation of cost be smaller than well-considered facts will warrant. There is often a temptation to cheapen the plans to a point below profitable efficiency, and to pass over cost items that will appear before the work is completed in order to make an attractive and impressive report. It is well for the engineer to exhibit an optimistic and resourceful temperament in dealing with such propositions, but it should

not blind him to the import of the facts which have a bearing upon them.

Preliminary Estimates. Estimates are of two kinds, preliminary and specific. The former are made at the outset to determine the feasibility of the project and its probable cost and returns should the work be carried out. In general, it is a comprehensive statement regarding the proposition as a whole in which the character of the contemplated improvement is set forth, and its cost, benefits and results given within reasonable limits of accuracy before definite and detailed information obtained from surveys and computations has been secured. It is necessary to consider the work in the divisions into which it naturally falls, but the law of general averages obtains to such an extent that the totals become approximately correct.

In making an estimate of the cost of a drainage survey and plan for any area, be it large or small, the divisions of the work which should receive separate consideration are:

First, Cost of field surveys, in which the time that will be required to cover the area in the manner previously decided upon must be estimated, including probable inclement weather (during which expenses will continue without a corresponding amount of work being done), the salary of field engineers and rodmen, wages of axmen and helpers, and cost of subsistence and travel.

Second, The time and force required for plotting the field records and making computations in the office, with corresponding salary charges.

Third, Remuneration of engineer for professional service and superintendence, either upon a commission or salary basis, and a margin to cover unforeseen contingencies.

A check estimate may be made by computing the cost

by the acre or mile unit, based upon figures derived from former experience. In any event, the character of the land as to contour and nature of soil to be covered has such an important bearing upon the cost of the survey that it should be critically examined by the engineer before he ventures a close estimate.

For Owner's Benefit. Estimates of the entire cost of a reclamation project, such as a landowner or company who contemplate the drainage or betterment of land will need, include all the leading divisions of the work and their total. Estimates may sometimes be made by an experienced man at a cost per acre, based on a comparison of the area under consideration with others whose cost is known. The work may be considered under the following heads:

Surveys, plans and specifications.
Material and transportation.
Contract price of construction.
Superintendence and inspection.
Subduing the land and preparing it for cropping.
Interest on the amount expended until returns can be obtained.

A common way of estimating the profits of such operations is to place the market value of the land at the time the estimate is made against its market value after draining, and designate the difference as the profit. This method partakes of the speculative feature of business, and does not always represent a return based upon the production of the land. Probably the most rational basis for estimating the value of the improvement is that of rentals after the land has been reclaimed, the annual rentals representing the interest on the total investment, including first cost, or value, draining, and all other improvements. In the case of wet lands, draining is, of course, the improvement that will govern the amount of returns, but does not represent the en-

tire investment. The amount of rentals varies with seasons and price of products, so that an average return of a number of years should be taken instead of one giving either large or small returns. A most important consideration is the inherent value of the soil and the character and value of the crops it will produce. The cost of draining may be the same for lands differing greatly in amount and value of yield. This fact is often only partially appreciated by the casual observer. A failure to estimate the entire investment required before the land is brought to a healthful and profitable condition sometimes leads to erroneous deductions regarding the financial merits of the proposition. The stability and permanence of the improvement is an important consideration and justifies the large first cost of lasting work which will yield a certain, though perhaps only a modest, annual return.

The betterment of an estate by draining the wet lands within its boundary, thereby raising the entire area to a uniform standard of production and general excellence, is an operation which can be represented as exceptionally attractive to landowners because of the quick and substantial returns for the outlay. In many cases almost the entire crop from reclaimed land may be placed to the credit of drainage, because the expense of operating and managing the land, taxes, etc., were the same before as after draining. In other words, such betterment virtually enlarges the estate or farm to the extent of the land which has been drained.

For Boards of Assessment. The preliminary estimates pertaining to a drainage district that are required for the information of the authority designated by the law to decide upon the merits of the project should include the following divisions of cost items:

Preliminary proceedings and surveys.
Location survey.
Amount of damages to be paid.
Construction called for by the petition.
Bridges.
Legal expense, engineering, superintendence, fees and contingencies.

These items may be canvassed and estimated roughly, one by one, and the total cost approximated. The laws do not ask that these estimates be made public, but they are a necessary preliminary to comply with the requirement that before a petition for drainage is granted it shall be shown that the project will be conducive to the public welfare and that the benefits in general will be greater than the cost.

A corresponding estimate of benefits may be taken up along the following lines:

Character, area and value of the land included in the petition.
Effect of the proposed work upon health conditions in the district.
Addition to public revenues from increase of taxable property.
Betterment of transportation facilities throughout the district.
Benefit to farms by construction of outlets.
Addition to farm profits and consequent appreciation of property.
Opportunity for better social and educational privileges.

In the attempt to assign a money value to these benefits, the temptation is to substitute general statements and platitudes for definite reasons, figures and argument. It is the judgment of the author that while definite financial benefits over and above the estimated cost of the work should be shown, in order to satisfy the requirements of the law, many others which have great weight may be appropriately named. The health benefits in some localities are most important, and are really sufficient to warrant the undertaking. An effort

should be made to arrive at well considered conclusions upon that phase of the proposition. The betterment of roads and the encouragement of residents in the district to make permanent and sightly improvements, with a commendable regard for rural embellishment, should have weight, though their definite worth in money is not easily established. While the lands that are improved must be charged with the cost of draining, on the ground that they will pay the cost to the owners by increased production, the incidental advantages of such improvements will always appeal strongly to those who are contemplating such undertakings.

Specific Estimates. These are made after definite quantities have been computed from data obtained by a survey. The price for which the several kinds and amounts of work can be performed must be estimated with reference to the conditions where the work is to be done. The engineer should view the work from the standpoint of the contractor taking into account the price of local labor and material. These vary so widely in different parts of the country, and the accessibility of the drainage area to towns and transportation facilities is such an important factor, particularly where small contracts are concerned, that no attempt will be made here to quote prices, but our efforts will be confined to classifying the different kinds of work and the units used in computing estimates.

The practical advantage of planning the work so that specific methods of execution that have previously been proved successful can be applied, has been emphasized. If the work is thrown open to contract, those having the facilities for doing it according to the methods upon which the plans are based will be attracted and submit a bid. If the information which is furnished concerning the physical conditions that are of in-

terest to the contractor is full and complete, a more intelligent and closer bid can be expected.

For Tile-Drains. After the total number of each size of tile has been computed and the length and depth of drains determined, the construction of the drains will fall under the following divisions:

1. **Cost of tile in car lots at the factory.**—In some cases the manufacturer will deliver tile, freight prepaid, at the railroad station nearest the work; in others the purchaser pays the freight. The former method is preferable. The quality of the tile should be specified and the shipper should stand breakage.

2. **Hauling from the factory or station.**—The contract for hauling should include distributing the tile along the several lines, according to schedule, in piles of 25 each. This work is best done at a specified rate per ton of 2,000 pounds. The length of haul, and nearness to the public road of land to be drained, as well as its firmness and ability of bearing a loaded wagon, will vary the rate. The contractor should be responsible for breakage in hauling.

3. **Digging ditches and laying tile.**—This work is done either by the linear rod or by the 100-foot section at a specified price for a ditch of minimum depth (which for ordinary farm drains is three feet for tiles up to and including 6 inches), and an additional price per inch for greater depths. Larger tile and deeper ditches are contracted for in sections of 100 feet of the specific sizes of tile and depth required, and includes laying the tile to grade and securing them in place. This work is sometimes done with a machine at a price per 100 feet of completed drain.

4. **Filling ditches.**—This is done at a rate per 100 feet, the price depending upon the width and depth of the ditch, the stickiness of the earth and whether there are stumps which will interfere with team work.

5. **Engineering and superintendence.**—This cost varies considerably, but usually runs from 6 to 10 per cent of the total. The engineering for work where small and comparatively inexpensive tile are used is as great as where large and expensive drains are constructed.

If the cost data have been quite accurately secured, but a small contingent extra need be allowed. It is best, however, to add 5 per cent to the total estimated cost under this head.

Open Ditch Systems. The unit in all considerations of earth excavation is the cubic yard. Computations of the amounts for ditches of different widths should be scheduled separately, as the price of excavation will depend in some degree upon the length of ditches of different widths as well as the total volume for the entire district. Ditches 30 to 40 feet wide and about 8 feet deep are more cheaply excavated per yard than either larger or smaller ditches, provided the contract is large. If the waste banks are to be spread for a road or shaped into a substantial levee, the cost will be greater than if the earth is deposited at random. If the excavation is to be made through a wooded territory, an estimate must be made for clearing the right of way, and for blasting large stumps. The accessibility of the proposed ditches for the delivery of the machinery is also a factor in the cost which must be considered by the engineer in estimating the cost of excavation. The following schedule of items should be estimated separately.

Excavation ditches, classified according to width and length, with amount of excavation in each.
Clearing right of way (if in timber), per acre or per linear mile.
Bridges, size and kind.
Legal expenses, regular and estimated litigation.
Engineering and superintendence.
Contingencies, commissioner's and clerk's fees.

In submitting the estimates, the engineer should describe the measure of efficiency which may be expected from the proposed ditches as fully as possible, for many drainage projects that are carried out under the law are but partial reclamations, and ditches must later be increased in number and size in order to furnish the complete drainage.

Estimates of benefits should be made as suggested in a previous paragraph, substituting the totals in the specific estimate for those used in the preliminary or rough estimate.

Accounts and Records. The engineer's professional training is frequently deficient in account-keeping, in making orderly and comprehensive statements of expenses and cost, and in classifying information which will be useful for reference. The engineer should be a business as well as a professional man, and arrange his accounts in such clear and concise form as to commend them to men who are versed in practical methods of business. Carelessness in this regard is inexcusable in an engineer, and if one finds himself deficient in this respect it will be well worth while to become conversant with business forms and methods, and exercise more than ordinary care in preparing formal statements, estimates, and expense accounts that are required in connection with the several lines of work he may undertake. Suggestions of forms of reporting drainage work are given in the Statutes relating to drainage, and in various books purporting to assist the inexperienced along this line, though in many cases these may be improved upon and adapted to special requirements.

The engineer will find it to his interest to keep a card-index record of information upon drainage subjects, covering especially classified data on the cost of surveys which he has conducted or of which he has access to the

records, cost of construction under different conditions, examples of benefits of drainage, methods of assessments, cost of maintenance of work, and many other items which will at once suggest themselves when the matter is taken under consideration. Such data become a valuable working capital which he can quickly refer to at any time, and rightly gives him a reputation for being well versed and experienced in his profession.

Engineers' Charges. The character, magnitude and importance of the work, and the experience and reputation of the engineer should control his remuneration, as they do in other branches of engineering. It is to be regretted that this is frequently not the case. Owing to the manner in which drainage work has developed, the fees commonly charged by land surveyors have been made the basis of those allowed the drainage engineer, while the drainage laws of some States go so far as to fix a lower fee for the surveyor when he acts as engineer in drainage districts than when he runs out property lines.

It is obvious that the work of the drainage engineer and that of the surveyor is essentially different, and that the former should rank with that of other branches of engineering and command the rate of compensation given to others of its class. Many clients of drainage engineers recognize this and are willing to ignore the limitations set by law and allow a liberal fee proportionate to the importance of the work.

Competition by some calling themselves drainage engineers, who offer to perform the field work at rates which engineers of training and experience cannot meet, often results in the work going to low bidders, whose services would not be accepted were the clients informed as to the comparative merits of the competitors.

Trained and experienced reputable drainage engineers should adopt a scale of prices commensurate with

their integrity and skill in laying out and directing the various classes of drainage work as those in other branches of engineering are doing.

Two methods of making charges commend themselves and are adopted by such engineers. These are a per diem rate, and a percentage on the cost of the work. In either case the engineer's expenses are additional, and are paid by the client. For small projects or in consulting work, the per diem rate is, perhaps, the more common, and varies from $10 to $25 per day for the engineer in charge of field surveys, and from $50 to $100 per day for consulting work, depending always upon the importance and difficulty of the work and the reputation of the engineer.

The percentage method is employed in large and costly undertakings which will extend over long time and be subject to delays. The amounts vary according to the nature of the service from 1 to 2 percent for preliminary survey and report, depending upon the difficulty of the work and the reputation of the engineer, to 8 to 12 percent for full professional service, supervision and management, depending upon the reputation of the engineer, the difficulty of the work, and inversely upon its cost, the greater the cost the less the percentage, as the amount of engineering work required is not, as a rule, increased in proportion to the increase in cost. This is especially true in tile-drain projects where the same amount of engineering is necessary for the small sizes of tile as for the larger ones. Underdrainage plans, however, require more field work than open ditch or levee systems.

The percentages are computed on the entire cost of the completed work or upon the estimated cost pending completion, and are paid as the work progresses in such instalments as agreed upon.

A percentage basis may be adopted for one or more stages of the work, and a per diem or monthly charge for the remainder. And instead of one rate for the entire work, the various divisions may be charged different percents, as 1 percent for preliminary survey, 6 percent for construction survey, etc.

Code of Ethics. In the execution and direction of all classes of work the honorable engineer will give his best efforts and skill to his clients, and be strictly honest with all who are in any way connected with the work, at the same time treating with courtesy and fairness all brother engineers.

The following code of ethics, adopted by the American Institute of Consulting Engineers, of New York, is a standard which should be recognized by all reputable engineers:

It shall be considered unprofessional and inconsistent with honorable and dignified bearing for any member of The American Institute of Consulting Engineers:

(1) To act for his clients in professional matters otherwise than in a strictly fiduciary manner, or to accept any other remuneration than his direct charges for services rendered his clients, except as provided in Clause 4.

(2) To accept any trade commissions, discounts, allowances, or any indirect profit or consideration in connection with any work which he is engaged to design or to superintend, or in connection with any professional business which may be entrusted to him.

(3) To neglect informing his clients of any business connections, interests or circumstances which may be deemed as influencing his judgment or the quality of his services to his clients.

(4) To receive, directly or indirectly, any royalty, gratuity or commission on any patented or protected article or process used in work upon which he is retained by his clients, unless and until receipt of such royalty, gratuity or commission has been authorized in writing by his clients.

(5) To offer commissions or otherwise improperly solicit professional work either directly or by an agent.

(6) To attempt to injure falsely or maliciously, directly or indirectly, the professional reputation, prospects or business, of a fellow-engineer.

(7) To accept employment by a client while the claim for compensation or damages, or both, of a fellow-engineer previously employed by the same client and whose employment has been terminated, remains unsatisfied, or until such claim has been referred to arbitration, or issue has been joined at law, or unless the engineer previously employed has neglected to press his claim legally.

(8) To attempt to supplant a fellow-engineer after definite steps have been taken towards his employment.

(9) To compete with a fellow-engineer for employment on the basis of professional charges, by reducing his usual charges and attempting to underbid after being informed of the charges named by his competitor.

(10) To accept any engagement to review the work of a fellow-engineer for the same client, except with the knowledge or consent of such engineer, or unless the connection of such engineer with the work has been terminated.

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